NORMANDEAU ASSOCIATES, INC.

Environmental Consultants

1982 YEAR CLASS REPORT
FOR THE HUDSON RIVER ESTUARY
MONITORING PROGRAM

VOLUME 1. TEXT

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1.0 INTRODUCTION

1.1 BACKGROUND

Since 1973, Hudson River Utilities[a] have financed large-scale ecological studies designed to assess the environmental impact of power plant operation on the fish populations of the Hudson River estuary. These programs have provided an extensive data base on the estuarine ecosystem of the river. Most of the prior information consisted of commercial fish landings, water quality data, and limited ecological surveys.

A large percentage of this joint effort focussed on striped bass (*Morone saxatilis*), white perch (*Morone americana*), and Atlantic tomcod (*Microgadus tomcod*). The principal objectives of these programs were (1) to assess the effect of power plant cooling water withdrawal from the river on the aquatic biota and (2) to develop a clearer understanding of the major aspects of the life history and population dynamics of Hudson River fish species. The results of these efforts were summarized by McFadden *et al.*, (1978), Texas Instruments Incorporated (TI, 1977, 1978a, 1979a, 1980a,b, 1981) and Battelle (1983).

The Hudson River Settlement Agreement was executed in December 1980 and became effective in May 1981. This agreement was a compromise out-of-court settlement, culminating 17 years of legal controversy between the Utilities and the United States Environmental Protection Agency in regard to Section 316(b) of the Clean Water Act requiring the Utilities to convert from once-through cooling to cooling towers (Docket No. C/IIWP7701). The main emphasis of the settlement agreement is on

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[a] Consolidated Edison Company of New York, Inc. (Con Edison), New York Power Authority, Orange and Rockland Utilities, Inc., Niagara Mohawk Power Corporation, and Central Hudson Gas and Electric Corporation.

mitigative measures to offset power plant impacts on the aquatic environment, with the ultimate goal being the protection of the Hudson River fisheries resources (Christensen *et al.*, 1981).

The Settlement Agreement included a monitoring program that was consistent with requirements of state and federal regulatory agencies concerned with the protection of the river's resources. The primary function of the monitoring program is to evaluate the success of mitigation in decreasing mortality associated with impingement and entrainment of fish species.

1.2 ICHTHYOPLANKTON AND JUVENILE FISH PROGRAMS

Several programs have been implemented since 1973 to assess the distribution and abundance of 12 selected fish species in the Hudson River estuary. These include 10 designated by the United States Environmental Protection Agency as representative and important species in monitoring programs at one or more Hudson River power stations; and two additional species, important ecologically and commercially (Table 1.2-1). Among these fisheries programs are three which focus on the early life stages, and have been conducted throughout the tidal portion of the estuary from the George Washington Bridge to Troy Dam above Albany.

The Longitudinal River Survey has been conducted to provide information on abundance, distribution, and population dynamics of eggs, larvae, and early juveniles of the selected species. This ichthyoplankton survey has utilized an epibenthic sled and a Tucker Trawl, both equipped with 505-µm mesh nets. The same gear, fitted with coarser (3000 µm) mesh, has been utilized in the Fall Shoals Survey to provide data on the relative abundance, distribution and movements of young-of-the-year and older fish. And finally, a Beach Seine Survey has yielded data on relative abundance, distribution and movements of juvenile and older fish in the shore zone.

TABLE 1.2-1. SELECTED FISH SPECIES FOR HUDSON RIVER ECOLOGICAL STUDIES.

A. REPRESENTATIVE AND IMPORTANT SPECIES	
Morone saxatilis	striped bass
Morone americana	white perch
Microgadus tomcod	Atlantic tomcod
Alosa pseudoharengus	alewife
Anchoa mitchilli	bay anchovy
Cynoscion regalis	weakfish
Ictalurus catus	white catfish
Notropis hudsonius	spottail shiner
Acipenser oxyrhynchus	Atlantic sturgeon
Acipenser brevirostrum	shortnose sturgeon
B. ECOLOGICALLY AND COMMERCIALLY IMPORTANT	
Alosa sapidissima	American shad
Alosa aestivalis	blueback herring

1.3 YEAR CLASS REPORT SERIES

As part of the Utilities' monitoring program, a series of reports has been prepared to summarize and synthesize information on the key fish species of the Hudson River. These reports present data on the early life stages of various species, including spatial and temporal abundance patterns observed in the estuary, to explain possible reasons for changes in abundance in the adult populations. The first of these reports was the First Annual Multiplant Report (TI, 1975) which combined the riverwide sampling approach of a study begun in 1973 associated with the proposed Cornwall pump-storage facility with an empirical estimation of individual and combined impacts of five electric generating stations on striped bass, white perch, and Atlantic tomcod.

In 1974, the multiplant effort was refined and renamed the Year Class Report (TI, 1977) to emphasize a "fish year", an 18-month period from January of the spawning year through June of the following year, which would include a full year's growth of the new year class for striped bass and white perch as well as for tomcod. The 1975 report (TI, 1978a) examined in greater detail patterns of abundance and distribution of the early life stages for the 1975 year class, but excluded direct impact estimates. The 1976 report (TI, 1979a), started to focus on ecological relationships of selected fish populations. The 1977 and 1978 reports (TI, 1980a,b) examined the concept of life history studies as a tool in the evaluation of power plant effects. The 1979 report (TI, 1981) further expanded the life history and distributional studies to include nine other species, and extended the analysis to include predictions of impact based on population age structure and age-specific survival. It also included statistical analysis of biocharacteristic data available from 1973 to 1979 for the three initial key species.

The 1980 and 1981 Year Class Report (Battelle, 1983) was the first report after the Settlement Agreement and was a continuation of life history and population dynamics studies of selected Hudson River fish species. It also included the first year (1981) in which the length of the sampling season was reduced to focus on specific periods within the first year of life. These periods had been previously identified as indicators of the effects of the mitigative measures on the populations of the selected species.

This 1982 Year Class Report represents the ninth in the series of year class reports. The primary objective of this report is to present and discuss the results of the Longitudinal River ichthyoplankton and Fall Shoals/Beach Seine juvenile surveys. This effort adds to the historical data base provided by previous year class reports by describing the major aspects of early life history and population dynamics of the 1982 year class of selected fish species. As in 1981, sampling effort was directed at detecting major changes in the populations based on abundance and distribution of early life stages and juvenile year class abundance of the selected species. Also included in this report is an evaluation of the analytical method used to provide an index of year class strength for striped bass and white perch.

1.4 REPORT ORGANIZATION

The 1982 Year Class Report is organized into five major text sections. Section 2.0, Methods and Materials, details the field and laboratory procedures used in the collection, identification, and processing of specimens. A complete description of all analytical methods used is included. Section 3.0, Water Quality, describes the general patterns of water quality parameters measured during the study period. Section 4.0 discusses the spatiotemporal distribution and relative abundance of various life history stages of the selected fish species listed in Table 1.2-1. This includes all early life history stages of striped bass, white perch, and American shad; the late larval stage and juvenile stage of Atlantic tomcod; the egg and larval stages of clupeids not identified to species; and the juvenile and older stages of blueback herring, alewife, bay anchovy, weakfish, white catfish, spottail shiner, Atlantic sturgeon, and shortnose sturgeon.

Section 5.0 presents and discusses growth and mortality estimates for the late larval and juvenile stages of striped bass, white perch, American shad, Atlantic tomcod, and bay anchovy. Section 6.0 deals with annual abundance (combined standing crop) indices for juvenile striped bass and white perch in the summer and fall. In association with this section are additional analyses regarding (1) evaluation of the present method of calculating abundance indices for striped bass and white perch, (2) a recommended refinement of this method; and (3) a method for calculating confidence intervals of the combined standing crop indices.

2.0 METHODS AND MATERIALS

2.1 FIELD AND LABORATORY PROCEDURES

In 1982, sampling programs were conducted for ichthyoplankton and/or juvenile fish from 10 May to 14 October in the tidal portion of the Hudson River between the George Washington Bridge (River Mile 12; km 19.3) and the Federal Lock at Troy (RM 152; km 246.2). Sampling was stratified among 12 geographic regions (Figure 2.1-1). Those 12 regions were further subdivided into strata based on depth: (1) shoals, that portion of the river from the shore to a depth of 6 m at mean low tide; (2) bottom, that portion, excluding the shoals, that is within 3 m of the bottom; and (3) channel, that portion that is not considered to be shoals or bottom (Figure 2.1-2). Sampling programs in 1982 were identical to those of 1981, including an ichthyoplankton survey (Longitudinal River Survey), and two juvenile fish surveys (Fall Shoals Survey and Beach Seine Survey). A river-wide water quality monitoring program, modified from previous studies, was conducted to provide associated environmental data.

2.1.1 Longitudinal River Survey

All available strata from the 12 geographic regions between RM 14 and 140 (km 22.5-225.2) were sampled (Table 2.1-1). Samples were collected in consecutive weekly sampling periods (river runs) from early May to early July (Table 2.1-2). Sampling was conducted during the day during the first six river runs and at night during the last three in order to decrease gear avoidance by post yolk-sac larvae and juveniles.

Sampling effort within each geographic region was determined by using a stratified random design. Effort was allocated to regions and strata based upon the distribution of the early life stages from previous years. Location and depth of each regional sample were randomly selected within each region and stratum.

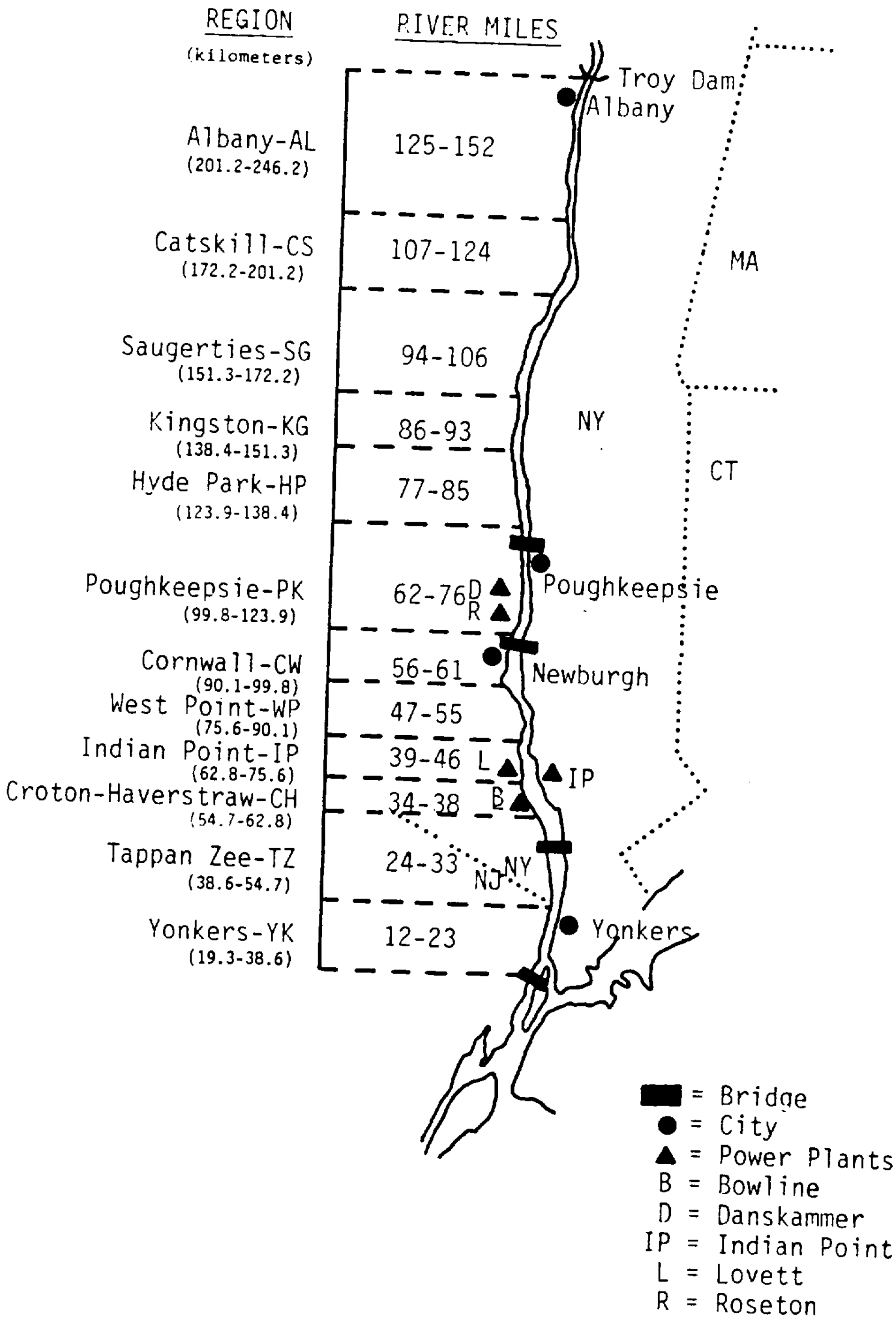


Figure 2.1-1. Location of 12 geographical regions (with river mile and kilometer boundaries) used during field sampling programs in the Hudson River estuary, 1982.

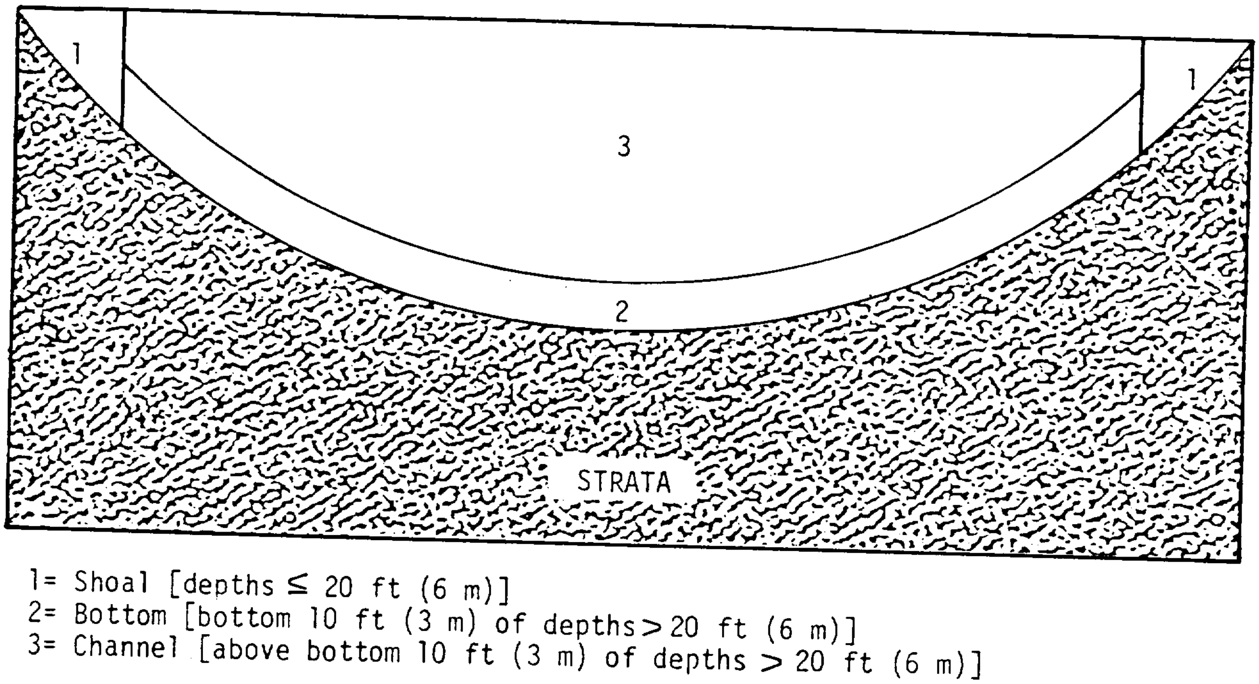


Figure 2.1-2. Cross section of Hudson River estuary showing strata sampled in 1982 by the Longitudinal River and Fall Shoals Surveys.

TABLE 2.1-1. STRATA SAMPLED BY ICHTHYOPLANKTON AND FALL SHOALS SURVEYS WITHIN THE TWELVE GEOGRAPHIC REGIONS OF THE HUDSON RIVER ESTUARY DURING 1982.

GEOGRAPHIC REGION		RIVER MILE[a]	AVAILABLE STRATA[b]		
			BOTTOM	CHANNEL	SHOAL
Albany	(AL)	125-152(201.2-246.2)	X	**	**
Catskill	(CS)	107-124(172.2-201.2)	X	X	**
Saugerties	(SG)	94-106(151.3-172.2)	X	X	**
Kingston	(KG)	86-93(138.4-151.3)	X	X	**
Hyde Park	(HP)	77-85(123.9-138.4)	X	X	**
Poughkeepsie	(PK)	62-76(99.8-123.9)	X	X	**
Cornwall	(CW)	56-61(90.1-99.8)	X	X	X
West Point	(WP)	47-55(75.6-90.1)	X	X	**
Indian Point	(IP)	39-46(62.8-75.6)	X	X	X
Croton-Haverstraw	(CH)	34-38(54.7-62.8)	X	X	X
Tappan Zee	(TZ)	24-33(38.6-54.7)	X	X	X
Yonkers	(YK)	12-23(19.3-38.6)	*	X	X

a = River Mile represents the area between mile points upriver from the Battery in New York City: (e.g., RM 1 = the area between mile point 1 and mile point 2). Number in parentheses indicates kilometers

b X = Stratum sampled

* = Not sampled due to obstructions

** = Not sampled - stratum too limited

TABLE 2.1-2. WEEKLY SAMPLE ALLOCATIONS FOR THE LONGITUDINAL RIVER ICHTHYOPLANKTON SURVEY, HUDSON RIVER ESTUARY, 1982.

REGION	WEEKS BEGINNING 10 MAY[a] AND 17 MAY[a]				WEEKS BEGINNING 24 MAY[a], 31 MAY[a], AND 7 JUNE[a]				WEEKS BEGINNING 14 JUNE[a], 21 JUNE[b], 28 JUNE[b], AND 5 JULY[b]			
	SHOAL	BOTTOM	CHANNEL	TOTAL	SHOAL	BOTTOM	CHANNEL	TOTAL	SHOAL	BOTTOM	CHANNEL	TOTAL
Albany	-	5	-	5	-	3	-	3	-	3	-	3
Catskill	-	3	3	6	-	3	3	6	-	3	3	6
Saugerties	-	3	3	6	-	5	3	8	-	4	2	6
Kingston	-	6	7	13	-	4	6	10	-	4	6	10
Hyde Park	-	9	11	20	-	7	12	19	-	5	9	14
Poughkeepsie	-	10	10	20	-	16	22	38	-	7	15	22
Cornwall	5	12	5	22	5	9	5	19	3	12	13	28
West Point	-	4	31	35	-	7	23	30	-	8	25	33
Indian Point	4	7	25	36	3	6	14	23	5	5	16	26
Croton-Haverstraw	6	3	6	15	5	4	4	13	4	6	6	16
Tappen Zee	3	4	3	10	3	4	4	11	3	5	6	14
Yonkers	3	-	3	6	3	-	3	6	1	-	8	9
TOTAL	21	66	107	194	19	68	99	186	16	62	109	187

[a] Daytime sampling
[b] Night sampling

Samples were collected with a 1-m^2 epibenthic sled (505-μm mesh) in the shoal and bottom strata and with a 1-m^2 Tucker trawl (505-μm mesh) within the channel and shoal strata. When used in the shoal stratum, the Tucker Trawl required a minimum river depth of 4 m (12 ft). The tow speed of the epibenthic sled was maintained at approximately 100 cm/sec and the Tucker trawl speed at approximately 90 cm/sec; as determined by the use of calibrated electronic flowmeters deployed along with the net. If the flowmeters failed in operation, then tow speed was estimated based on engine RPM.

Calibrated digital flowmeters were suspended within the net in order to determine sample volume. Standard tow duration was 5 min unless large numbers of fish were consistently captured, at which time 2-min tows were made. At the completion of each tow, the net was rinsed and the contents of the collection cup examined.

All larger specimens (yearling and older) were identified, enumerated by length class (Table 2.1-3), and released. All Atlantic and shortnose sturgeons were released alive if possible. The remaining sample was preserved in 10% formalin and returned to the laboratory for processing.

Fish eggs, larvae, and juveniles collected in the ichthyoplankton surveys were separated from the detritus and inorganic material after staining the sample with rose bengal and then rinsing it through a 375-μm mesh. Organisms were placed in vials containing 5% formalin according to taxonomic group (species or family) and stage of development (eggs, yolk-sac larvae, post yolk-sac larvae, and young-of-the-year; Table 2.1-4). If the sample was estimated to contain over four thousand fish eggs or bay anchovy larvae, then the sample was split to not less than 1/8 of the original using a Folsom plankton splitter. Larvae of species other than bay anchovy were always sorted from the whole sample. Specimens were then identified to the lowest practical taxonomic level (usually species) and enumerated by life stage. In each sample striped bass, white perch, and American shad were measured for

TABLE 2.1-3. LENGTH CLASS DIVISION, HUDSON RIVER ESTUARY, 1982.

LENGTH CLASS	TOTAL LENGTH RANGE (millimeters)
1	0 - Division I
2	Division I+1 - Division II
3	Division II+1 - 250
4	$\geq$ 251

NOTE: Division I and Division II represent empirically determined cut-off lengths which are intended to represent the upper limits for young-of-the-year and yearling age groups, respectively. Division I and Division II were determined separately for each species and updated periodically throughout the year as part of the impingement program at the Indian Point power station.

TABLE 2.1-4. CRITERIA USED FOR STAGING ICHTHYOPLANKTON.

EGG	This embryonic stage commences with spawning and continues until hatching.
YOLK-SAC LARVA	This stage begins with hatching and continues until the development of a complete and functional digestive system.
POST YOLK-SAC LARVA	This stage begins with the initial development of a complete digestive system and continues until a full complement of adult fin rays is acquired.
YOUNG-OF-THE-YEAR	This stage begins when the full complement of adult fin rays is acquired and continues until 31 December of the year spawned. (Also referred to as juvenile.)

total length (TL). When available, up to 30 organisms per species were measured, including at least 10 per life stage (yolk-sac, post yolk-sac, and young-of-the-year). When fewer than 10 specimens for a particular life stage were encountered the remainder of the quota was allocated to the remaining available life stages. The identification process was aided by reference collections and the appropriate taxonomic literature.

2.1.2 Fall Shoals Survey

Two hundred samples per river run (Table 2.1-5) were collected biweekly within RM 14-140 from August through October. Samples were taken at night and location and depth were randomly allocated. Samples within the shoal and bottom strata were collected with a 1-m^2 epibenthic sled with a 3000-µm mesh net with a conical fyke inside the enlarged cod end. The channel stratum was sampled with a 1-m^2 Tucker trawl, also with a 3000-µm mesh net. Standard tow duration was 5 min. As with the ichthyoplankton surveys, digital flowmeters were employed to determine sample volume and electronic flowmeters were used to determine tow speed. Tow speed for the epibenthic sled and the Tucker trawl was maintained at approximately 150 cm/sec.

TABLE 2.1-5. BIWEEKLY SAMPLE ALLOCATION FOR FALL SHOALS SURVEY, HUDSON RIVER ESTUARY, 12 AUGUST - 9 OCTOBER 1982.

GEOGRAPHIC REGION	SHOAL EPIBENTHIC SLED	BOTTOM EPIBENTHIC SLED	CHANNEL TUCKER TRAWL	TOTAL
Albany	+	8	+	8
Catskill	+	15	6	21
Saugerties	+	12	6	18
Kingston	+	9	6	15
Hyde Park	+	6	4	10
Poughkeepsie	+	5	3	8
Cornwall	5	5	3	13
West Point	+	5	3	8
Indian Point	6	5	3	14
Croton-Haverstraw	16	8	3	27
Tappan Zee	30	8	8	46
Yonkers	7	+	5	12
Total	64	86	50	200

+ = stratum too limited for sampling.

At the completion of a tow the contents of the collection cup (or cod end) were rinsed. All yearling and older fish were identified, enumerated by length class (Table 2.1-3), and released. All Atlantic and shortnose sturgeons were released alive if possible. The remaining sample (juveniles) was preserved in 10% formalin and returned to the laboratory for identification and enumeration by species. In each biweekly period, a maximum of 20 young-of-the-year per region of the selected species were measured for total length. This length quota was filled by randomly selecting a maximum of 5 specimens per sample. In those regions where biweekly sample allocations were less than ten (Table 2.1-5), then a maximum of 10 specimens per sample were selected.

2.1.3 Beach Seine Survey

Sampling was conducted biweekly from August through October. A total of 100 samples per sampling period were randomly collected (Table 2.1-6) using a 30.5-m beach seine (Table 2.1-7). Sampling locations within each region and time period were selected randomly. The seine was deployed by attaching one end to the boat and held onto the shore at the other. The net was set as the boat moved perpendicular to the shore. It was then hauled clockwise in a semi-circular path until it reached shore. The completed tow would sweep an area of approximately 450 m^2 (TI, 1981).

Samples were sorted and enumerated by species and length class (Table 2.1-3). All yearling and older fish were processed in the field and then released. All Atlantic and shortnose sturgeons were released alive if possible. All juveniles were preserved in 10% formalin and returned to the laboratory for identification and enumeration by species. Length measurements were taken for all selected species and recorded to the nearest mm TL. Fish were selected randomly and allocated by region and sample.

TABLE 2.1-6. BIWEEKLY SAMPLE ALLOCATION FOR BEACH SEINE SURVEY, HUDSON RIVER ESTUARY 16 AUGUST - 14 OCTOBER 1982.

GEOGRAPHIC REGION	RIVER MILES	NUMBER OF BEACHES SAMPLED
Albany	125-152	7
Catskill	107-124	10
Saugerties	94-106	9
Kingston	86-93	5
Hyde Park	77-85	5
Poughkeepsie	62-76	5
Cornwall	56-61	6
West Point	47-55	5
Indian Point	39-46	5
Croton-Haverstraw	34-38	14
Tappan Zee	24-33	24
Yonkers	12-23	5
Total	12-152	100

TABLE 2.1-7. DIMENSIONS OF 30.5-METER SEINE USED IN THE BEACH SEINE SURVEY, HUDSON RIVER ESTUARY, 1982.

Number of wings	2
Length of wings	12.2 m (40 ft)
Depth of wings	2.4 m (8 ft)
Wing mesh stretch	1.9 cm (0.75 in.)
Length of bag	6.1 m (20 ft)
Depth of bag	3 m (10 ft)
Bag mesh stretch	0.9 cm (0.375 in.)

2.1.4 Water Quality

Water quality data (temperature 0.1°C, dissolved oxygen 0.1 mg/ℓ, and conductivity 1.0 µS/cm) were collected to provide associated environmental data for each survey. For each of the ichthyoplankton and Fall Shoals surveys a total of 164 water quality samples were collected per sampling period (Table 2.1-8). Water chemistry measurements were made *in situ* at fixed river miles and strata. Surface and bottom measurements were taken in the shoals, and surface, mid-depth, and bottom measurements were taken in the channel (Table 2.1-9). The *in situ* probes were lowered over the side with an appropriate amount of cable so that it would be within 1 m of the bottom. After the bottom measurements were taken the probe was raised to the mid-depth region (channel only) and then to 1/2 m below the surface for surface measurements.

During the Beach Seine survey, 100 water quality samples were collected per sampling period (river run) in conjunction with the seine hauls from August through October. Water quality measurements were taken near the surface approximately 50 feet (15 m) offshore, after the seine haul was completed.

2.2 ANALYTICAL PROCEDURES

2.2.1 Preparation of Data for Analysis

The data used to prepare the 1982 Year Class Report were received from Con Edison on a magnetic tape. The tape contained three files of 1982 data and the software programs developed and used for the preparation of the 1980-1981 Year Class Report.

All data sets were created in a pseudo-hierarchichal SAS file structure compatible with previous year class reports. Level 3 contains general sample information (date, time, site, river run, etc.); level 4 contains information on the gear type; level 5 has information on the

TABLE 2.1-8. WATER QUALITY SAMPLE ALLOCATION AND FIXED SITE LOCATIONS (RIVER MILE) FOR 1982 ICHTHYOPLANKTON AND FALL SHOALS SURVEY, HUDSON RIVER ESTUARY.

GEOGRAPHIC REGION	SITE LOCATIONS[a] SHOALS	CHANNEL	SAMPLING STATIONS EAST SHOAL	CHANNEL	WEST SHOAL	NUMBER OF SAMPLES PER REGION
Albany	-	127,131,135,138	-	4	-	12
Catskill	-	109,114,118,122	-	4	-	12
Saugerties	-	96,99,102,105	-	4	-	12
Kingston	-	87,89,91,93	-	4	-	12
Hyde Park	-	78,80,82,84	-	4	-	12
Poughkeepsie	-	63,67,71,75	-	4	-	12
Cornwall	59	56,57,59,61	1	4	1	16
West Point	-	49,51,53,55	-	4	-	12
Indian Point	43	40,42,43,46	1	4	1	16
Croton-Haverstraw	36	35,36,37,38	1	4	1	16
Tappan Zee	29	25,27,29,32	1	4	1	16
Yonkers	19	14,17,19,22	1	4	1	16
TOTAL			5	48	5	164

[a] River Mile Location

-Dash indicates that no sample was taken due to limited stratum.

TABLE 2.1-9. WATER QUALITY PARAMETERS MEASURED DURING EACH SURVEY, HUDSON RIVER ESTUARY, 1982.

SURVEY	DEPTH	DISSOLVED OXYGEN (mg/l)	TEMPERA-TURE (°C)	CONDUCTIVITY (µS/cm)
ICHTHYOPLANKTON				
Shoals	S,B	a	a	a
Channel	S,M,B	a	a	a
FALL SHOALS				
Shoals	S,B	b	c	c
Channel	S,M,B	b	c	c
BEACH SEINE	S	b	c	c

S - Surface
M - Mid-depth
B - Bottom

[a] - Hydrolab Model 4041 Digital *in situ* water quality analyzer.
backup: Martex Model V *in situ* water quality analyzer.

[b] - YSI Model 57 Dissolved oxygen.

[c] - Beckman RS5-3 meter
backup: YSI Model 33 S•C•T meter.

catch, such as the number of specimens of each species and life stage taken or water quality data; level 6 contains length data on individual specimens. The magnetic tape was unloaded and duplicated using an IBM 4381 computer system. A quality control audit was then performed to determine the accuracy of the transferred data against the original data sheets. The audit procedure insured an accuracy level of 1% AOQL by using a Military Standard lot inspection plan MIL-STD-105D (ASQCSC, 1981).

2.2.2 Software

To ensure comparability between the 1982 Year Class Report and those of previous years, all analytical procedures were identical to those described by Texas Instruments Incorporated (TI) in the 1974-1979 year class reports. Due to differences in computer systems and the presentation of the final output, most of the software programs used for the 1980-1981 report could not be used without some modifications; however, all algorithms used by the modified programs were identical to those used previously.

2.2.3 Calculations

Equations referred to in this section are presented in Appendix A.

2.2.3.1 Water Quality

To assess the effects of abiotic variables on the population dynamics of the Hudson River fish populations, water quality data for each week were averaged by region and by estuary segment for each parameter (dissolved oxygen concentration, temperature, and conductivity). Regional means were weighted by stratum volumes and segment means were weighted by regional volumes (Equations 1 and 2).

2.2.3.2 Abundance and Standing Crop

Catch data from ichthyoplankton, Fall Shoals, and Beach Seine surveys were used to estimate the relative abundance (density or catch per unit effort) and the total abundance (standing crop) of the 1982 year class of the selected species in the river. A standard error was calculated for each estimate.

The following description of abundance calculations is presented in terms of standing crop. Every standing crop value has a corresponding density or catch per unit effort (CPUE), which is simply the standing crop divided by the volume (or, in the case of Beach Seine data, area) of that part (e.g., stratum or region) of the river. For the sake of consistency in presentation among species, while providing comparability to previous year class reports, both standing crop and density (or CPUE) data are tabulated in Appendix B.

Ichthyoplankton and Fall Shoals density estimates were calculated for each tow by life stage and taxon from the catch data and tow volume (Equation 3). Density estimates were then averaged by stratum within region (Equation 4). A standing crop estimate was then calculated by sampling period for each stratum within each region by multiplying mean density by river volume (Equation 5). Strata which were not sampled were accounted for by adding their volumes to adjacent sampled strata before converting densities to standing crops (Table 2.2-1). These standing crop estimates were combined to give totals for each of the three strata (Equation 6), for each of the 12 regions (Equation 7), and for the entire river (Equation 8).

Standing crop is an estimate of the number of individuals of a particular species in an area at a given time. Stratum standing crops show the relative abundance of a species in each stratum and can be used to show relative movements within each region. Because of large differences in river volume among strata and among regions, a higher standing crop in one area does not necessarily mean a higher concentration or density there.

TABLE 2.2-1. STRATA VOLUMES (MILLION M^3) USED IN STANDING CROP CALCULATIONS FOR ANALYSIS OF HUDSON RIVER 1982 ICHTHYOPLANKTON AND FALL SHOALS SURVEYS.

	STRATA						
GEOGRAPHIC REGION	BOTTOM	%[c]	CHANNEL	%[c]	SHOAL	%[c]	TOTAL ACROSS
Albany	13.5	19.0	32.0[b]	45.0	25.6[b]	36.0	71.1
Catskill	42.3	26.3	83.9	52.2	34.5[b]	21.5	160.7
Saugerties	42.8	24.3	113.1	64.2	20.3[b]	11.5	176.2
Kingston	35.5	25.1	93.7	66.2	12.3[b]	8.7	141.5
Hyde Park	32.0	19.3	131.2	79.3	2.3[b]	1.4	165.5
Poughkeepsie	63.2	21.2	229.0	76.8	6.0[b]	2.0	298.2
Cornwall	36.8	26.3	94.9	67.9	8.1	5.8	139.8
West Point	26.0	12.5	178.8	86.2	2.6[b]	1.3	207.4
Indian Point	33.4	16.0	162.3	77.9	12.6	6.1	208.3
Croton-Haverstraw	32.5	22.0	61.3	41.5	53.9	36.5	147.7
Tappan Zee	62.1	19.3	138.0	42.9	121.7	37.8	321.8
Yonkers	59.3[a]	25.9	143.4	62.5	26.6	11.6	229.3

[a] For analytical purposes this volume was added to the channel volume.
[b] For analytical purposes these volumes were added to the bottom stratum volumes.
[c] % stratum of total strata for that region.

For the 30.5-m beach seine, catch-per-unit-effort (CPUE), defined as the number of individuals per haul, was calculated to estimate relative abundance, for each of the 12 regions (Equation 9). Standing crop estimates were calculated for each region by multiplying CPUE by the ratio of regional shore zone surface area to the area sampled by one seine haul (Equation 10), and then combined to estimate standing crop for the entire river (Equation 11). The shore zone surface area (m^2) from 0 to 3 m deep for each of the 12 regions was calculated by TI (1981) from USGS depth contour maps (Table 2.2-2). The area sampled by a seine was estimated as 450 m^2 by TI (1981), based on empirical measurements in addition to an analysis of how the area swept is affected by variation in the distance along the shore between the two ends of the net when it initially closes.

Distribution indices were computed by life stage to determine trends in geographic and temporal distributions. The geographic and temporal distribution indices for each life stage were calculated as the relative percentage of standing crop contained by each region or by each weekly (or biweekly) sampling period (Equations 12 and 13). The higher the index value, the higher the standing crop was in a particular region or sampling period relative to the surrounding regions or sampling periods during the same year.

2.2.3.3 Growth and Mortality

Procedures used to estimate growth and mortality rates were consistent with those of previous year class reports as described by TI (1981) when the appropriate data were available. Some modifications were made, particularly in the estimation of growth, to accommodate differences in the data due to changes in sampling schedule. In the discussion of the results (Section 5.0), additional details of these modifications are given, along with their rationale and a description of how they differ from previous methods.

TABLE 2.2-2. EXTENT OF SHORE ZONE SURFACE AREA (M^2) FROM 0-3 M DEEP IN 12 GEOGRAPHIC REGIONS OF HUDSON RIVER ESTUARY USED TO CALCULATE STANDING CROP ESTIMATES FROM BEACH SEINE CATCHES IN 1982.

GEOGRAPHIC REGION	RIVER MILE	LENGTH[b]	SHORE ZONE SURFACE AREA (M^2)
Albany	125-152	28	6,114,000
Catskill	107-124	18	8,854,000
Saugerties	94-106	13	7,900,000
Kingston	86-93	8	3,874,000
Hyde Park	77-85	9	558,000
Poughkeepsie	62-76	15	3,193,000
Cornwall	56-61	6	4,793,000
West Point	47-55	9	1,186,000
Indian Point	39-46	8	4,147,000
Croton-Haverstraw	34-38	5	12,101,000
Tappan Zee	24-33	10	20,446,000
Yonkers	12-23	12	3,389,000
TOTAL	12-152		76,555,000

[b] in river miles.

Daily Growth Rate Estimated from Length Data

Mean lengths of larvae and early juveniles collected in ichthyoplankton samples were calculated for each sampling week by weighting the mean length for each stage by the abundance (standing crop) of that stage (Equation 14). The means were weighted in this manner because larvae and juveniles were not selected for measurement in proportion to their abundance. Mean lengths from fall juvenile sampling were used to estimate a logarithmic growth curve by linear regression (Equation 15). The date on which the mean length for the population reached 60 mm was then estimated from that logarithmic growth curve (Equation 16). Growth during the post-yolk sac and early juvenile stages was estimated by an exponential growth curve generated by linear regression of length data from the ichthyoplankton and fall juvenile sampling (Equation 17). From the exponential growth equation, an estimate was calculated of when the recruitment length was reached (Equation 18). The dates when the recruitment length and 60 mm were reached were used to estimate the average daily growth from hatching to recruitment length and from recruitment length to 60 mm (Equation 19).

A variation of this procedure was used to generate a second estimate of growth rates, using maximum lengths instead of mean lengths. For this, the exponential growth was estimated from ichthyoplankton data alone (Equation 17), without first calculating logarithmic growth based on juvenile data. Dates when recruitment length and 60 mm were reached were then calculated from the exponential relationship (Equation 18) and the corresponding growth rates were calculated from those dates (Equation 19).

Daily Mortality Rate Estimated from Population Decline

This method does not rely on length-at-age estimations and is appropriate when length data or the length-at-age relationship are unavailable, or for the late summer period when the variation in length at any particular age is much greater than it was in the larval and early juvenile stages. It utilizes standing crop estimates for successive weeks to measure of the rate of population decline.

The weekly abundance of larvae and early juveniles was estimated from ichthyoplankton samples (Equation 8). The weekly abundance of juveniles was estimated by the combined standing crop calculated from the Fall Shoals Survey and the Beach Seine Survey, which was adjusted to account for day-night catch differences and for gear efficiencies (see Section 2.2.3.4). The rate of population decline from the week of peak abundance was estimated by linear regression (Equation 20 and expressed as a daily mortality rate (Equation 21).

2.2.3.4 Annual Abundance Indices

Weekly Combined Standing Crop

To evaluate the overall strength of the 1982 Year Class for striped bass and for white perch, the total abundance of these species was examined during the late summer-early fall period. It was felt that the best way to estimate the size of the entire population of a fish species would be to combine data from more than one sampling gear, representing different habitats. Therefore, data from the ichthyoplankton, Fall Shoals, and Beach Seine surveys have been combined in previous year class reports (with appropriate adjustments made for gear type) to best present a quantitative estimate of juvenile abundance in the Hudson River estuary.

In 1982, however, ichthyoplankton sampling ended a month before the juvenile sampling began. Because of (1) the difficulty in making any meaningful estimates for the long period when there was no sampling in 1982, and (2) recruitment to the juvenile stage being far from complete by the end of ichthyoplankton sampling, the 1982 ichthyoplankton data do not contribute toward the combined standing crop analysis.

To calculate weekly standing crop estimates from biweekly samples, the missing weeks were estimated using the average of the previous week and the following week (Fall Shoals) or by using the previous week's value (Beach Seine). Missing strata were estimated by multiplying the density estimate from an adjacent sampled stratum by the river volume of the unsampled stratum. To avoid overlap between the shore zone (0-3 m) and shoal stratum (0-6 m), standing crops of shoal strata were reduced by 25% under the assumption that if the bottom slope is fairly uniform then the shore zone contains 25% of the water from 0 to 6 m deep.

The night/day catch ratio was used to adjust the shore zone estimate because the Beach Seine Survey was conducted during the day and the Fall Shoals Survey at night. The adjustment avoided excluding fish which might stay in deeper water during the day and move into the shore zone at night. This ratio, calculated when both night and day beach seine collections were made (1973, 1974, and 1978), was calculated to be 2.136 for striped bass and 1.685 for white perch (TI, 1981).

Catch efficiency adjustments were also included, because no particular gear type is 100% efficient in sampling. The estimated catch efficiency values of the 30.5-m beach seine, which were empirically derived (TI, 1978b, 1979b), are 0.255 for striped bass and 0.182 for white perch. Efficiency values for the epibenthic sled and Tucker trawl were assumed to be 50% based upon data presented by Kjelson and Colby (1977) and TI (1980b).

After the night/day and gear efficiency adjustments had been made, standing crops estimated by the two juvenile surveys were combined within each region (Equations 22 and 23). The regional combined standing crops for each week were then summed to give the weekly combined standing crop representing the entire river (Equation 24).

Combined Standing Crop Index

The weekly combined standing crops (CSC) were plotted and visually inspected to determine a period of peak abundance. A geometric mean of the peak CSC was then extrapolated to an equivalent standing crop on 1 August, using an assumed mortality rate of 0.4% per day (75% per year) (Equation 25).

This CSC index was also calculated by a variation of this procedure, in which CSC values for a 10-week period, beginning with the week which contained 1 August, were used to estimate an exponential mortality curve by linear regression (Equation 20, with t = days after 1 August, and N_o = CSC 1 August equivalent). A fall CSC index was calculated by linear regression of the CSC in the five-week period beginning with the week containing 1 September, and then calculating an estimate for 15 September from the resulting exponential curve (Equation 20, with t = days after 1 August, N_o = regression line intercept, and N_{45} = 15 September estimate = Fall CSC Index).

Weekly and Combined Standing Crop Index Confidence Intervals

Confidence limits for weekly CSC estimates of young-of-the-year striped bass and white perch were calculated from the product of standard error of the CSC estimate (Equation 24) and the t-statistic from Student's t-distribution. Degrees of freedom for selecting the appropriate t-statistic for 95% confidence limits must be estimated because the sample allocations used in the Long River/Fall Shoals Survey (Table 2.1-5) and Beach Seine Survey (Table 2.1-6) were relatively small in some strata and subject to variance heterogeneity among strata. A method for approximating the effective degrees of freedom in cases of heterogeneous variance among sampling strata is given by Cochran (1977:Equation 5.16). This method, however, requires an assumption of a normal distribution of the data (Cochran, 1977). This restriction applies to the sample densities and catch per unit effort data for Fall

Shoals and Beach Seine samples, respectively. The assumption of normality in striped bass and white perch data sets was tested using SAS PROC UNIVARIATE and the Kolomogorov D statistic (SAS, 1982). Confidence limits for data sets not satisfying the normality assumption were calculated using the theoretical maximum and minimum degrees of freedom (Cochran, 1977) to establish the widest and narrowest confidence limits possible. Widest limits were based on the fewest degrees of freedom (df); one less than the number of samples in the smallest stratum or 2 df. Narrowest confidence limits were based on the maximum number of degrees of freedom for the weekly CSC estimate; one less than the total number of samples collected in a week or 299 df.

Confidence limits for the annual CSC index were computed as point estimates about the predicted 1 August or 15 September CSC index for significant exponential regression equations (Equation 20) using Equations 26 and 27 (Sokal and Rohlf, 1981). If a significant regression was not found for the fall CSC index, a geometric mean CSC for the five-week period symmetric about 15 September was calculated, and confidence limits were obtained from the product of the simple standard error of the geometric mean and student's t-statistic for df of one less than the number of weeks in the mean.

2.2.4 Quality Control

A quality assurance program was designed to insure accurate analysis of the data and a high quality level for the finished report. Specific quality control procedures were performed to verify the reliability and validity (accuracy, precision, and completeness) of all report figures and report tables. These procedures used the MIL-STD-105D normal inspection level sampling plans for inspection by attributes (ASQCSC, 1981). Lot sizes were the total number of calculations or data points for a set of data, table or figure. Randomly selected data points were traced to the original data or verified computer analysis. In the case of calculations, the appropriate number of calculations was recalculated utilizing original data. If the recalculated value differed from the original value by greater than rounding error, that data point was rejected. If the number of rejected data points equaled the reject number for the sampling plan at a 1% AOQL, the entire data set was recalculated. A quality assurance audit was performed to insure that all quality control procedures were correctly and completely implemented.

3.0 WATER QUALITY

Water temperature, dissolved oxygen concentration and conductivity were measured in conjunction with the Longitudinal River Ichthyoplankton, Fall Shoals and Beach Seine Surveys. Monthly average freshwater flow data for the Hudson River at Green Island, N.Y. (approximately RM 153; km 246) were obtained from the United States Geological Survey, Water Resource Division in Albany, N.Y. Each of these abiotic environmental variables influences population dynamics of Hudson River fishes, and consequently represents an important factor in determining the ultimate size and distribution of those populations.

Water quality data obtained from the Longitudinal River Ichthyoplankton and Fall Shoals Surveys were averaged by stratum (shoal and channel from surface to bottom) and region (1-12) and presented as weighted mean values by sampling period and segment (lower, middle and upper estuary). These larger segments of the study area represent areas with relatively distinct morphometrics and physical and chemical environments (TI, 1981). The lower estuary extends from RM 12 through RM 38 and encompasses the Yonkers, Tappan Zee and Croton-Haverstraw sampling regions. The middle estuary extends from RM 39 through RM 76, and includes the Indian Point, West Point, Cornwall and Poughkeepsie regions. The remaining five sampling regions, Hyde Park, Kingston, Saugerties, Catskill and Albany, comprise the upper estuary, from RM 77 through RM 153. The water quality data set obtained from the beach seine survey was averaged by region and also weighted to obtain weighted mean values by segment. This data set is presented separately since it did not conform in time or location to the data from the Longitudinal River and Fall Shoals Surveys.

Freshwater flow at Green Island, N.Y. was presented as the monthly average by year from 1971 through 1982,and as a long-term monthly average encompassing the years 1918-1981. Monthly freshwater flow as a percent of the long-term monthly average was determined for 1982 data.

3.1 TEMPERATURE

Similar water temperatures were recorded for the lower, middle and upper segments of the Hudson River estuary during the May through October 1982 sampling period (Figure 3.1-1). On average, water temperature varied between segments by only about 1.5^{o}C. In each segment, water temperature increased gradually from May to August and subsequently declined. Peak water temperatures in the lower and upper segments were recorded during the first half of August ($\bar{x}$ = 25.2^{o}C and 25.1^{o}C, respectively) and in the middle segment during the second half of August ($\bar{x}$ = 29.3). The largest temperature difference between segments was recorded during this later period when the middle estuary was 4^{o}C and 6^{o}C warmer than the upper and lower segments, respectively. The warm water responsible for this difference was located primarily in the Indian Point and West Point regions of the middle estuary (33.0 and 29.8^{o}C, respectively; Appendix C, Table C-1). This was the only sampling period in which a large temperature difference (>2^{o}C) occurred among estuary segments. Peak water temperatures recorded in the upper and lower segments were slightly lower than peak temperatures recorded during the 1979 through 1981 surveys (26.5-28.5^{o}C); while the higher temperatures of the middle estuary exceed the range of peak temperatures during these previous years.

Shore zone temperatures recorded during August, September and October as part of the Beach Seine Survey (Figure 3.1-2) were similar to temperatures reported for the shoal and channel. Shore zone data also indicated that temperatures were higher in the middle estuary than either the upper or lower estuary.

3.2 DISSOLVED OXYGEN

Mean dissolved oxygen concentrations during the May through October sampling period fluctuated in each segment by less than 4.0 mg/ℓ (Figure 3.2-1). The largest variability occurred in the lower

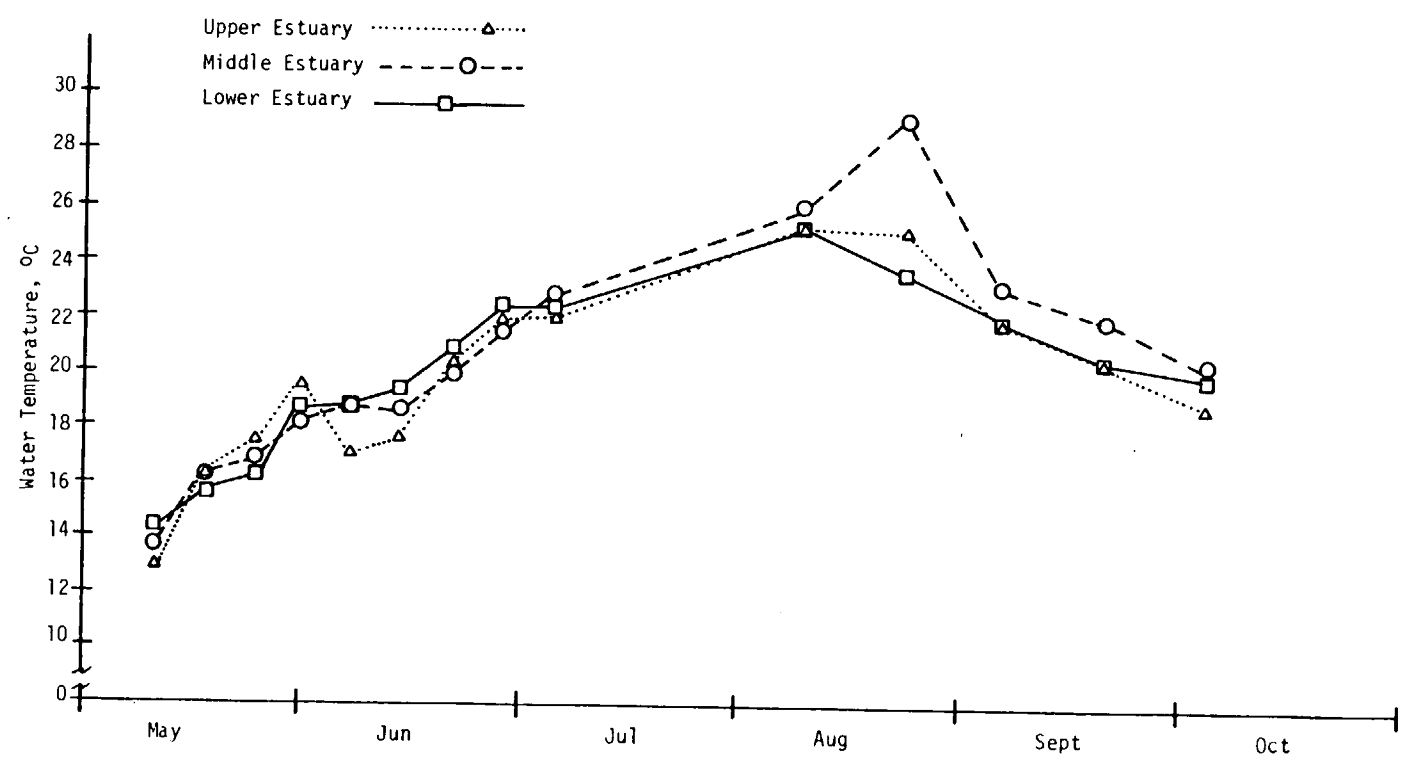


Figure 3.1-1. Weekly mean water temperature (^{o}C) in the lower, middle and upper segments of the Hudson River estuary, 1982. Weighted mean of shoal, bottom, and channel strata.

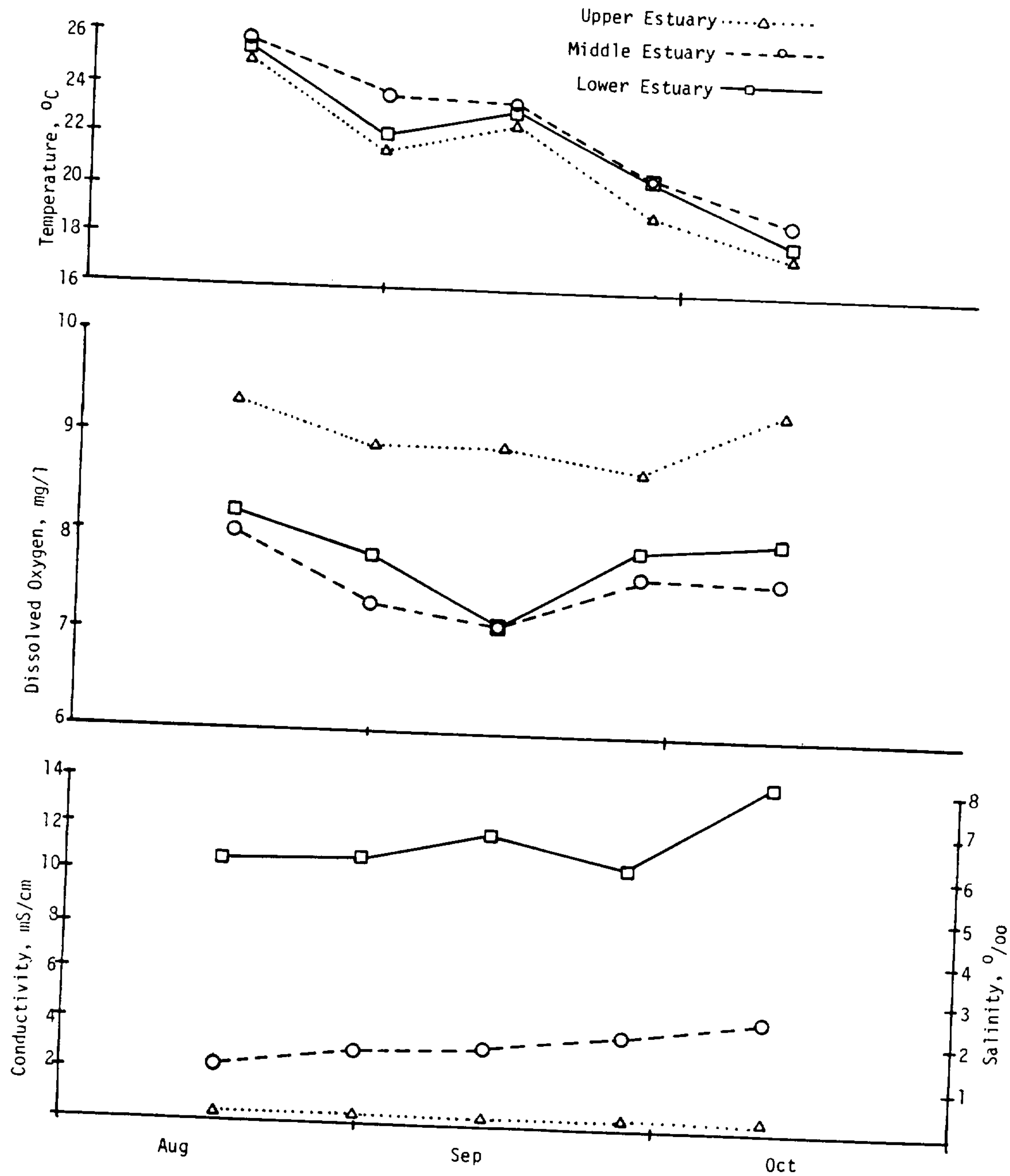


Figure 3.1-2. Weekly mean temperature, conductivity and dissolved oxygen in the shore zone of the lower, middle and upper segments of the Hudson River estuary, 1982.

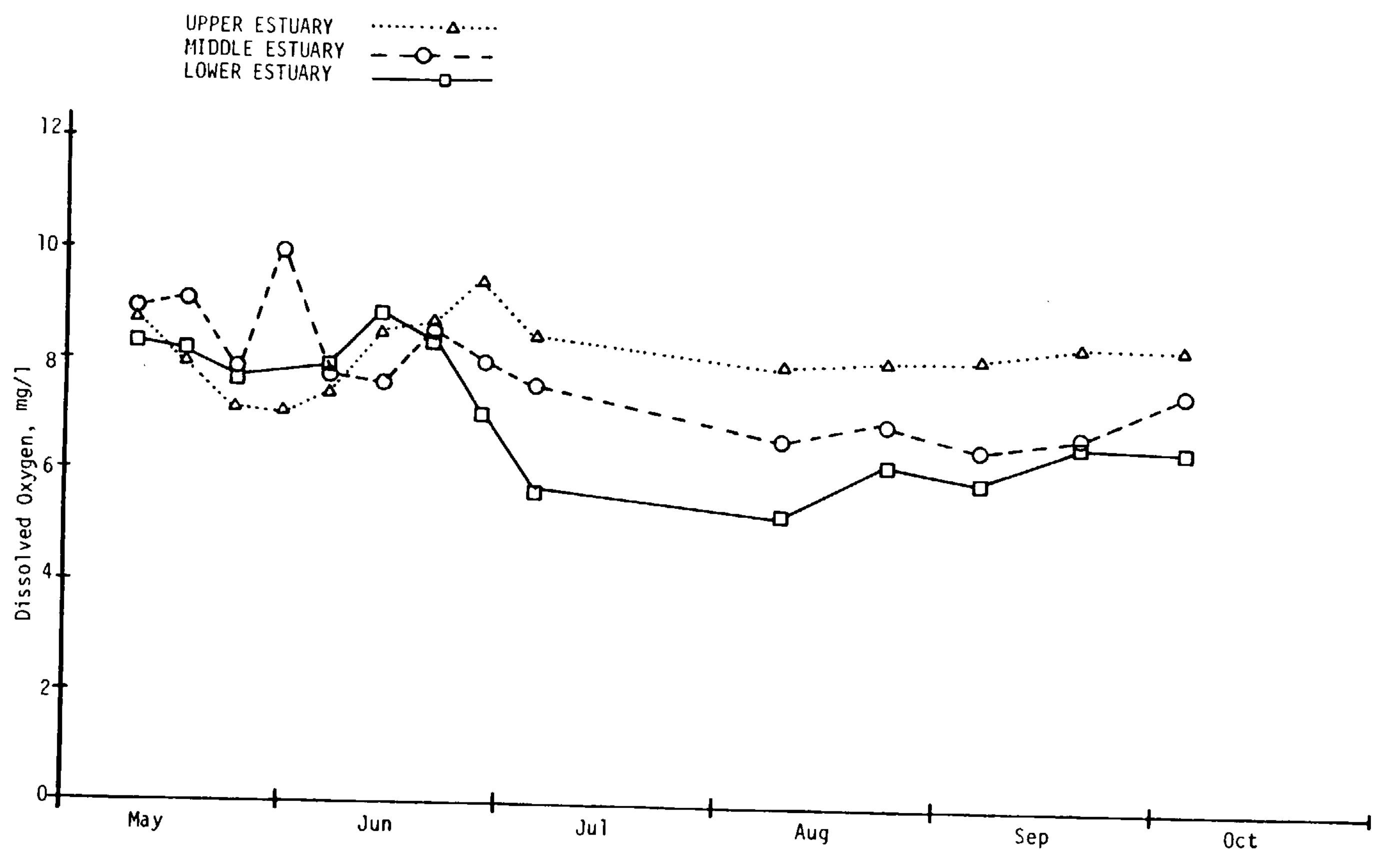


Figure 3.2-1. Weekly mean dissolved oxygen (mg/l) in the lower, middle, and upper segments of the Hudson River estuary, 1982. Weighted mean of shoal, bottom, and channel strata.

estuary where dissolved oxygen dropped from a high of 8.9 mg/ℓ in mid-June to 5.3 mg/1ℓ in early August. This low concentration corresponded in time to the peak water temperature for the segment. Dissolved oxygen subsequently rose through early October as water temperatures cooled. A similar trend in dissolved oxygen concentrations was observed in the middle estuary, but dissolved oxygen did not drop to the extent observed in the lower estuary despite somewhat higher water temperatures. The upper estuary showed the least variability in dissolved oxygen concentration with a difference of only 2.5 mg/ℓ between the lowest and highest mean concentrations for the period. In this segment dissolved oxygen was lowest during late May/early June (7.0 mg/ℓ) and subsequently rose to a high for the period during late June (9.5 mg/ℓ). Excluding this oscillation, upper segment dissolved oxygen concentrations only fluctuated between 8 and 9 mg/ℓ during the May through October sampling period and were usually higher than concentrations in the lower two segments.

Shore zone dissolved oxygen concentrations in each segment (Figure 3.1-2) were, on average, 1 mg/ℓ higher than concentrations in the shoal and channel. This may have been the result of greater turbulence nearshore.

3.3 CONDUCTIVITY

As anticipated, mean conductivity varied considerably between the lower, middle and upper estuary (Figure 3.3-1). Conductivity to salinity conversions are presented in Table 3.3-1 to facilitate comparisons between these two closely-related environmental variables. In the upper estuary, mean conductivity was consistently less than 0.4 mS/cm during the May through October sampling period. Similarly low values were recorded in past years in this segment of the estuary, which experiences only minimal salt water influence. Seasonal conductivity variations in the lower and middle estuary were also similar to previous years, and as expected, followed a pattern that was essentially opposite to freshwater flows (Figure 3.3-2). In the middle estuary, conductivity

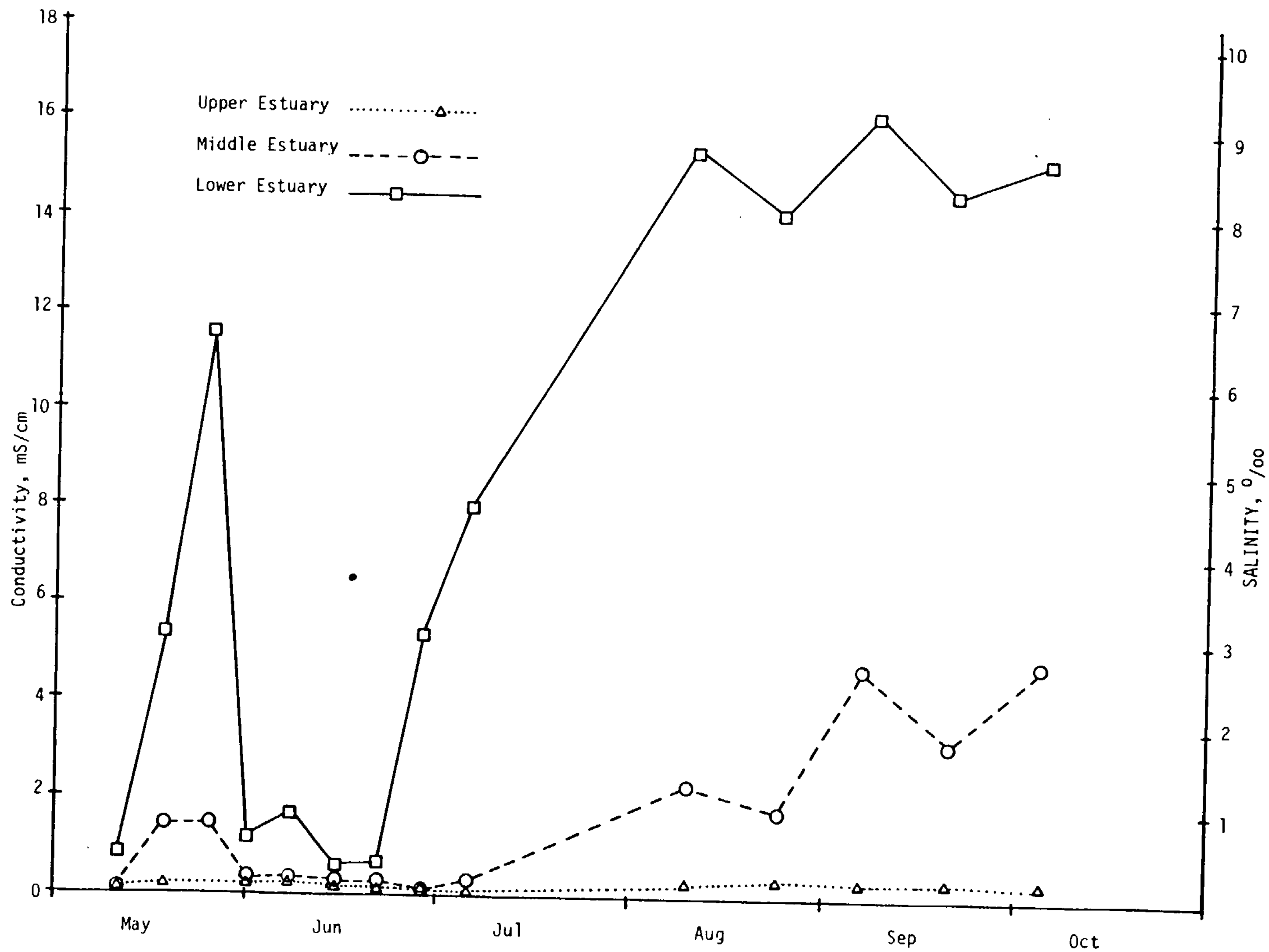


Figure 3.3-1. Weekly mean conductivity (mS/cm) in the lower, middle, and upper segments of the Hudson River estuary, 1982. Weighted mean of shoal, bottom and channel strata.

TABLE 3.3-1. CONDUCTIVITY TO SALINITY CONVERSION TABLE[a].

CONDUCTIVITY (mS/cm)	SALINITY[b] ($^{o}/oo$)	CONDUCTIVITY (mS/cm)	SALINITY[b] ($^{o}/oo$)
0.50	0.28	16.00	9.39
1.00	0.56	16.50	9.70
1.50	0.84	17.00	10.01
2.00	1.13	17.50	10.32
2.50	1.40	18.00	10.63
3.00	1.69	18.50	10.94
3.50	1.98	19.00	11.25
4.00	2.27	19.50	11.57
4.50	2.55	20.00	11.88
5.00	2.84	20.50	12.20
5.50	3.13	21.00	12.52
6.00	3.42	21.50	12.83
6.50	3.71	22.00	13.15
7.00	4.00	22.50	13.47
7.50	4.29	23.00	13.79
8.00	4.59	23.50	14.12
8.50	4.88	24.00	14.44
9.00	5.17	24.50	14.76
9.50	5.47	25.00	15.09
10.00	5.77	26.00	15.74
10.50	6.06	27.50	16.73
11.00	6.36	30.00	18.40
11.50	6.66	32.50	20.10
12.00	6.96	35.00	21.83
12.50	7.26	37.50	23.58
13.00	7.56	40.00	25.37
13.50	7.86	42.50	27.19
14.00	8.17	45.00	29.05
14.50	8.47	47.50	30.94
15.00	8.78	50.00	32.87
15.50	9.08	52.50	34.83
		55.00	36.83

[a]From TI (1981)

[b]Salinity = $-100 \ln\left(1- \frac{C_{25}}{178.5}\right)$

where, C_{25} = conductivity ($mS \cdot cm^{-1}$e $25^{o}C$)

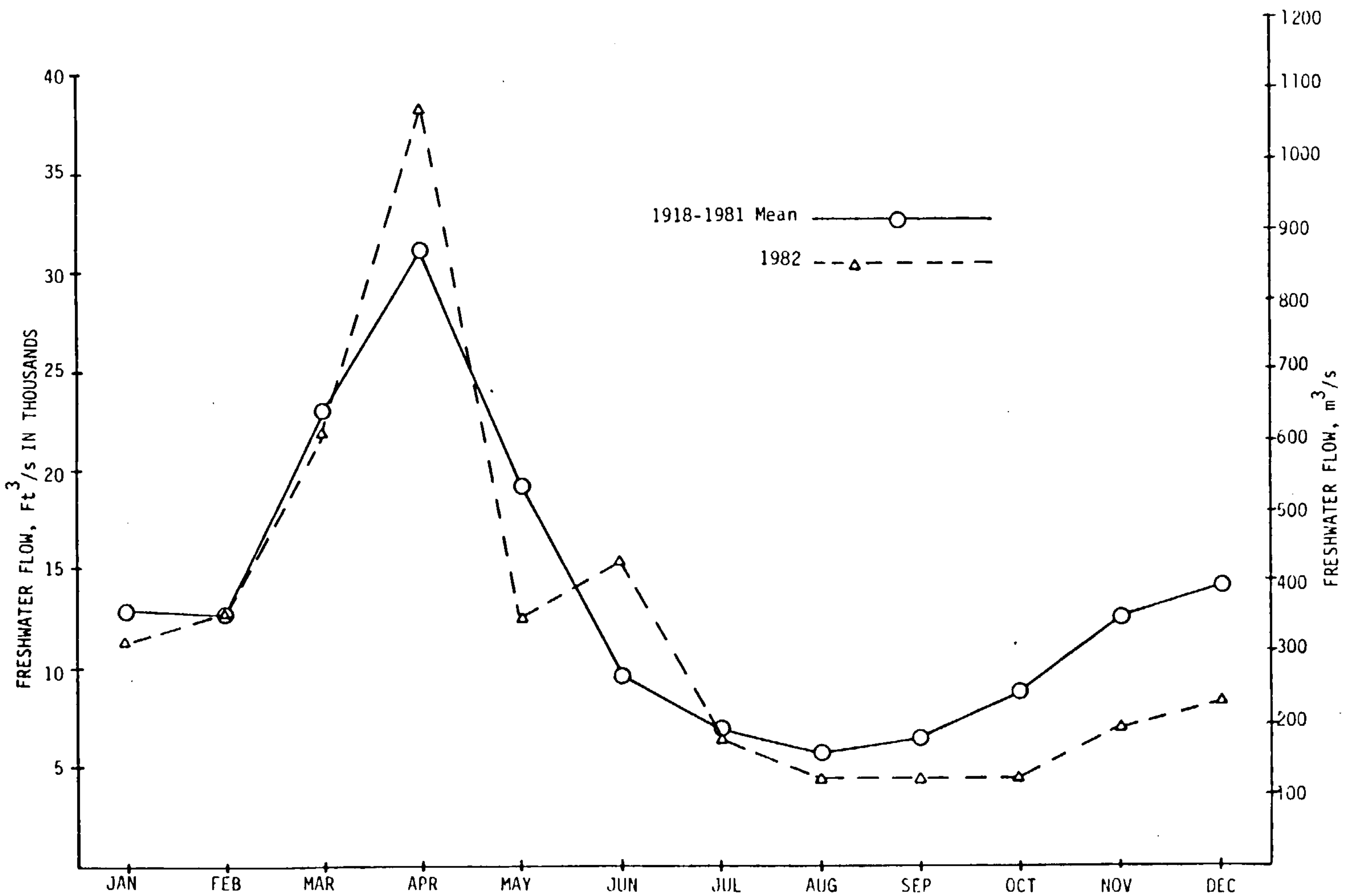


Figure 3.3-2. Monthly averaged freshwater flows at Green Island, N.Y. for 1982 and long-term (1918-1981).

increased from a low of less than 0.1 mS/cm during late June to 3.1-4.8 mS/cm during September and early October. This late summer/early fall peak was similar to the late summer peak observed in 1981 when conductivity in the middle segment reached 6.0 mS/cm. In the lower estuary, mean conductivity values were lowest during May and June (<1.7 mS/cm), with the exception of a strong pulse in mid-May (11.6 mS/cm), and highest during August through early October (14.1-16.1 mS/cm). Slightly higher late summer conductivity values were recorded in 1980 and 1981 when mean conductivity values reached approximately 20 mS/cm. The lower values in 1982 corresponded to slightly higher freshwater flows than in 1980 and 1981, and consequently, a lesser degree of saltwater incursion.

Conductivity values recorded in the shore zone of the middle and upper estuary (Figure 3.1-2) were similar to conductivity values in the shoal, bottom and channel strata (Figure 3.3-1). In the lower estuary, however, conductivity values in the shore zone were less than in the shoal and channel by about 3.5 mS/cm.

3.4 FRESHWATER FLOW

Freshwater flow rates of the Hudson River at Green Island, N.Y. during 1982 showed a major pulse during April followed by a gradual decline to lowest levels in August, September and October (Table 3.4-1 and Figure 3.3-2). This trend in freshwater flow was consistent with the pattern for the long-term (1918-1981) average monthly flows. Freshwater flow rates during the January-July period ranged from 65.4 to 158.3% of normal and averaged about 104% of normal for the period (Table 3.4-2). The April pulse was 123% of the long-term average for the month and was exceeded in flow by only four other months during the past eleven years (March 1977 and 1979, April 1977 and May 1972) (Table 3.4-1).

TABLE 3.4-1. MONTHLY AVERAGED FRESHWATER FLOWS AT GREEN ISLAND, N.Y. (cubic feet per second)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARLY STATISTICS MEAN*	MAX	MIN
1971	9002	12110	20220	37270	35240	7334	6233	8929	9315	7811	7291	17000	14830	37270	6233
1972	13410	10930	26860	37960	40520	29630	18380	7616	6309	7291	26150	27010	21017	40520	6309
1973	26210	20460	29410	30960	27600	13050	10390	5591	4791	5650	8280	26420	17410	30960	4791
1974	22010	18640	20730	30170	22960	8791	11780	6359	10390	9049	17180	19380	16433	30170	6359
1975	19070	19370	23680	25580	20000	12970	7464	8966	17030	23400	22500	18780	18211	25580	7464
1976	14740	31260	31690	36760	31800	15220	15280	14630	9573	23230	17930	14080	21311	36760	9573
1977	7956	8032	43540	40560	16020	7325	5735	5439	14410	30140	23440	26550	19161	43540	5439
1978	26310	14120	21870	33560	18730	9954	4643	5976	6195	8608	8020	10700	14053	33560	4643
1979	20162	11850	44240	38120	19570	8318	4644	5248	7800	11080	16420	15190	16920	44240	4644
1980	9044	4527	22380	26430	9676	6796	5080	4596	4170	5520	8540	9632	9708	26430	4170
1981	5239	30060	12340	13579	11576	5973	4943	4717	8224	16129	13903	11276	11356	30060	4717
1982	11330	12750	21890	38300	12510	15240	6421	4396	4310	4394	6926	8244	12178	38300	4310

*Mean of monthly means weighted by number of days/month.

Source: United States Geological Survey
Water Quality Data: New York State

TABLE 3.4-1. (Continued)

LONG-TERM SUMMARY: 1918-1981

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Max	33940	31260	56314	51610	40820	29630	22505	14630	21612	30140	32810	33489	
Mean**	12947	12580	22854	31100	19139	9626	6882	5575	6435	8608	12608	14033	13532
Min	3200	3033	6301	10250	4830	3252	2875	2456	2845	2967	3270	4335	
N =	64	64	64	64	64	64	64	64	64	64	64	64	

**Mean is simple mean of monthly means.

Source: United States Geological Survey
Water Quality Data: New York State

TABLE 3.4-2. MONTHLY FRESHWATER FLOW AT GREEN ISLAND, N.Y. AS A PERCENT OF LONG-TERM (1918-1981) AVERAGE.

MONTH	1982
Jan	87.5
Feb	101.4
Mar	95.8
Apr	123.2
May	65.4
Jun	158.3
Jul	93.3
Aug	78.9
Sep	67.0
Oct	51.0
Nov	54.9
Dec	58.7

During the second half of the year (August-December), flow rates dropped below normal and ranged from only 51 to 79% of the long-term monthly mean and averaged 62% of normal. Low flows during this period resulted in an average annual flow rate for 1982 that was 10% below the long-term annual mean.

4.0 SPATIAL AND TEMPORAL DISTRIBUTION AND ABUNDANCE OF SELECTED SPECIES

4.1 STRIPED BASS

The striped bass, *Morone saxatilis* (Walbaum), is an anadromous bass in the family Percichthyidae. It is a euryhaline and widespread species, with an Atlantic coast distribution north to the St. Lawrence River and south to the St. Johns River in northern Florida and into the Gulf of Mexico. During the 19th century striped bass were introduced to the Pacific coast in the vicinity of San Francisco and today range between the Canadian and Mexican borders. In the Hudson River, striped bass are observed throughout the estuary north to the Troy Dam in Albany (TI, 1981).

Adults may be found in salt, brackish, or freshwater. Those adults found in freshwater usually consist of stragglers or of spawning groups. When in salt water they remain relatively close to the shore, rarely being recorded over 16 kilometers offshore (Raney, 1976).

The spawning bass are usually located near the mouths of rivers just above brackish water, although some have been observed spawning up to 300 kilometers from any saltwater (Raney, 1976; Dovel, 1981). Areas of intense striped bass spawning appear to occur a short distance upstream from the limit of brackish water (Rathjen and Miller, 1957). Spawning in the Hudson River occurs in the early spring, beginning with the upstream migration into freshwater in the area between Croton-Haverstraw (RM 34) and West Point (RM 55). Clark (1968) has shown that the Hudson River, particularly that area in the vicinity of Haverstraw, is an important spawning area for the striped bass and that the stock produced there is an important fishery resource around New York Harbor and the western part of Long Island Sound.

After spawning is complete, some adults remain in the estuary, although most tend to leave and return to sea. During the fall months along the Atlantic coast, a massive southward migration to the wintering grounds in Chesapeake and Delaware Bays begins. Some of these southward migrants break off and enter lower reaches of the Hudson River. Here they remain to overwinter and spawn during the following spring.

Striped bass eggs are deposited near the surface in areas of strong currents ensuring that they not settle to the bottom, where a danger of suffocation is present (Bigelow and Schroeder, 1953). The eggs are spherical, semi-buoyant and non-adhesive. Eggs are 3-4 mm in diameter and hatch in 37 hours at a temperature of 21^{o}C (Rogers *et al.*, 1977).

The number of eggs released varies with the size of the female, with 100,000 eggs being produced by a 2-kg female and up to 5 million by a 25-kg female (Raney, 1976). Some females reach sexual maturity by Age IV, with virtually all being mature by Age IX. Most males reach maturity by Age II or III, with all reaching sexual maturity by Age IX.

On hatching, the larvae are approximately 2-5 mm in length, and begin to move into areas of low salinity. This seems to enhance their survivability and growth (Dovel and Edmunds, 1971). The yolk sac is absorbed in 6-7 days at which time the larvae have reached a total length of about 5.8 mm (Rogers *et al.*, 1977). During the first summer the young remain in small schools, feeding on small pelagic and benthic invertebrates and fish. The young are most commonly found in the shore zone and prefer sand or gravel beaches where the current is pronounced.

Distribution patterns of young-of-the-year in the Hudson River estuary have suggested that during the fall they move downstream, although tag return data have indicated relatively little movement among regions (TI, 1981). In some years this downstream movement may begin as early as late August for part of the population (TI, 1981). The juveniles are presumed to overwinter in the deeper parts of the lower estuary or farther seaward.

The striped bass is a powerful and fierce predator eating a variety of animal foods as juveniles and becoming increasingly piscivorous as they grow (Trent and Hassler, 1966). The striped bass is a long-lived species which often obtains a total length of 1100 mm and a weight of 14 kg (Bigelow and Schroeder, 1953).

4.1.1 Eggs

Striped bass eggs were already present in the Hudson River estuary when sampling began on 10 May, with mean densities of over 100/1000 m^3. The area of concentration was in the middle estuary and the extreme lower reaches of the upper estuary (RM 47-85). The peak concentration of striped bass eggs was in the West Point region (Figure 4.1-1), as it had been during 1974-1981 (TI, 1981; Battelle, 1983). This area of concentration is similar to that noted by Rathjen and Miller (1957). Striped bass deposit their eggs near the surface in areas of turbulent current. These semi-buoyant eggs are found in the entire water column from surface to bottom, with densities being greater near the bottom in areas of slow currents (Albrecht, 1964). The Hudson in the West Point region is relatively narrow, with strong currents and depths up to 36 meters. During the sampling season conductivity in this region averaged 0.45 mS/cm (range 0.03-2.0 mS/cm). Another concentration of eggs occurred further upriver, in the Poughkeepsie and Hyde Park regions (RM 62-85). Conductivity in this area was 0.132 mS/cm (<.1 $^{o}/oo$). In all cases, striped bass eggs were collected when the average conductivity was below 3.5 mS/cm (2 $^{o}/oo$). The distribution of eggs among river regions during the weeks of peak abundance shows a shift from the initial site of egg concentration (West Point) north to the Poughkeepsie and Hyde Park regions (Figure 4.1-2). Much of this movement can be attributed to an upriver movement of spawning adults to areas of lower salinities, but there may also be some passive transport of eggs due to tidal drift. Striped bass eggs are easily floated by agitation, can drift with the currents, and they are generally concentrated in near-bottom waters (Hardy, 1978) where the net tidal flow is likely to be upriver.

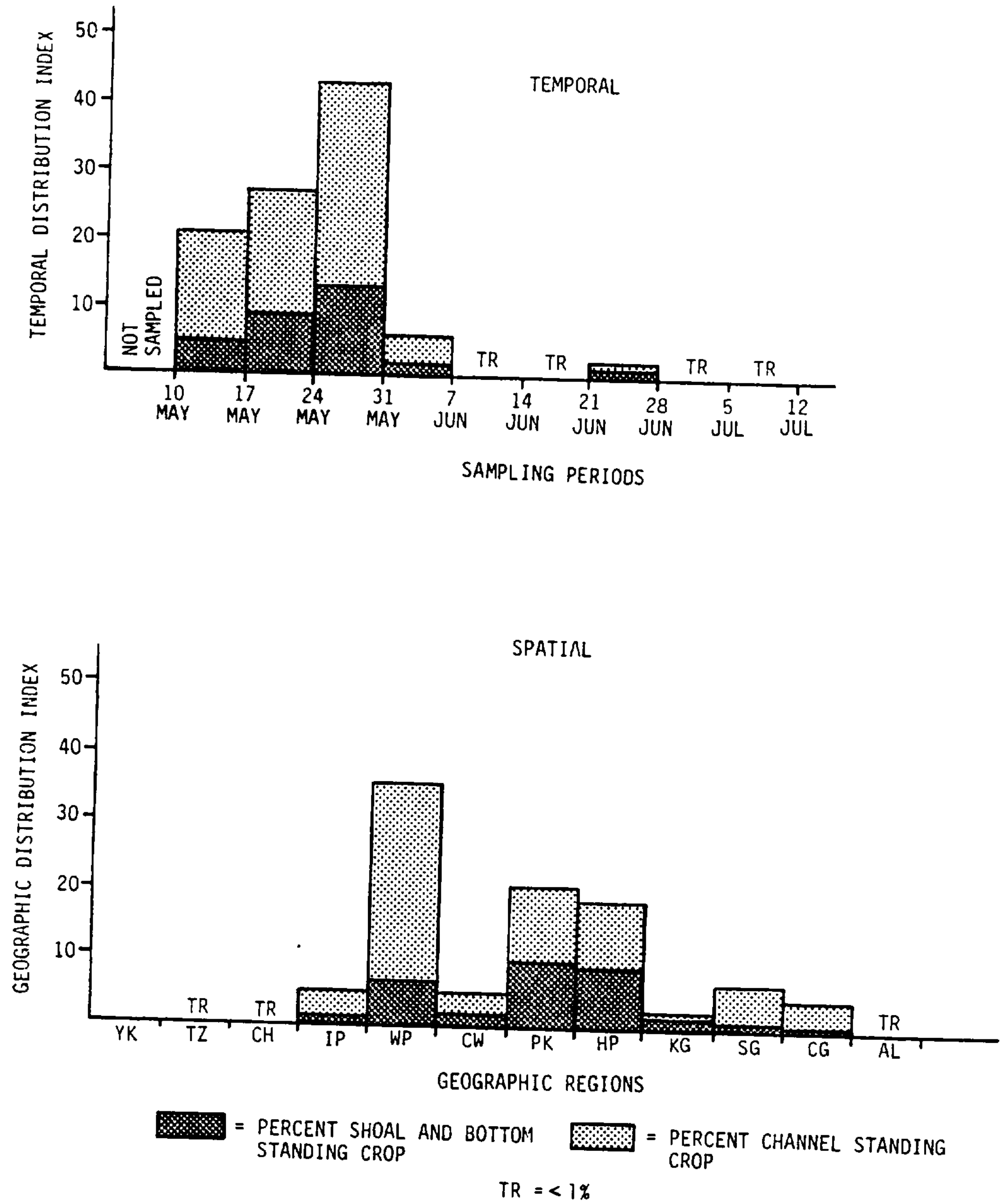


Figure 4.1-1. Patterns in distribution of striped bass eggs, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

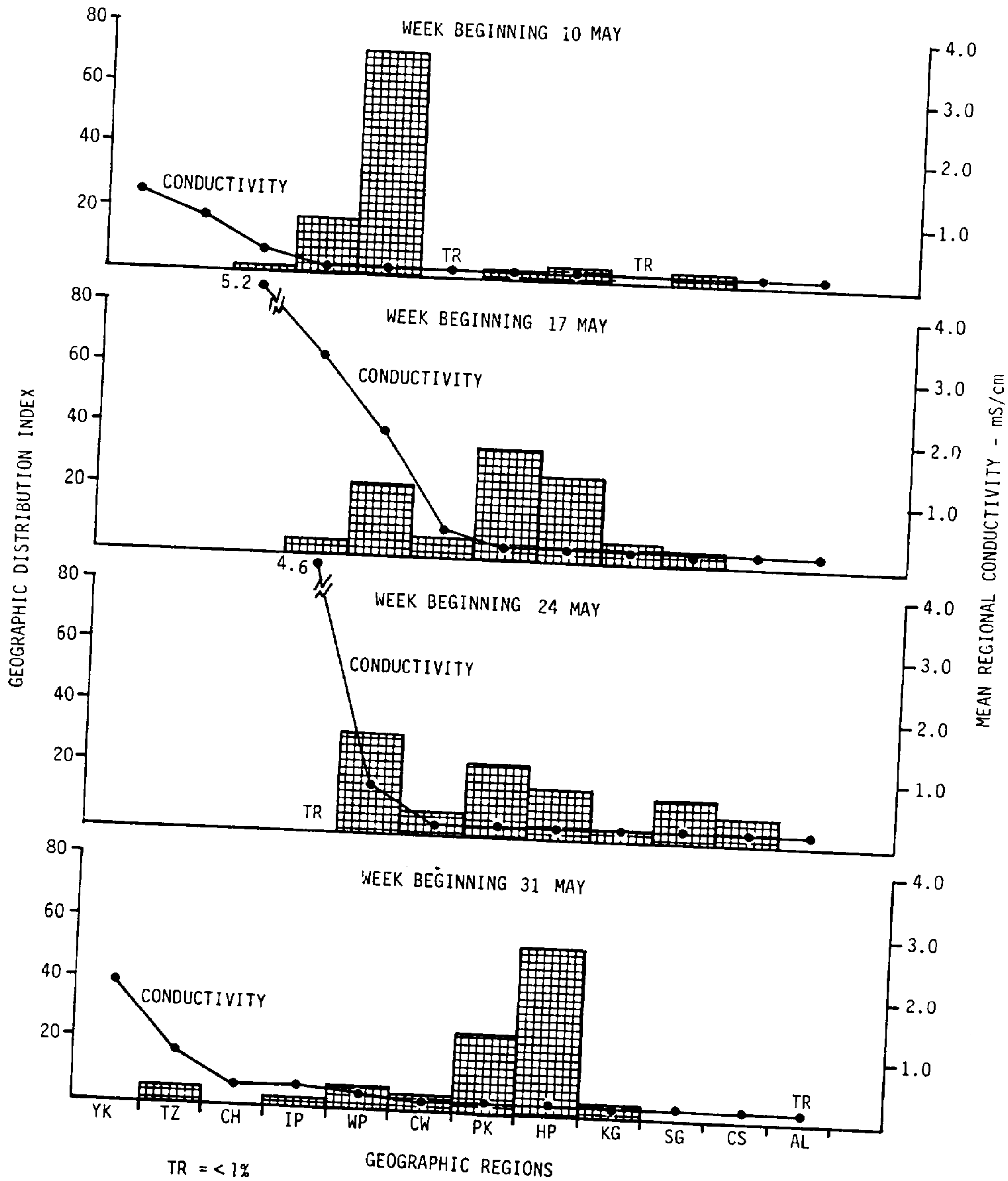


Figure 4.1-2. Weekly geographic distribution of striped bass eggs during the period of peak abundance and its relationship to conductivity, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

At the time the ichthyoplankton sampling began the water temperature in the middle estuary was 13°C, with a steady increase to 17°C, during the 4th week (24 May), when peak abundance of eggs was observed. At this temperature eggs would hatch in about 55 hours (Rogers *et al.*, 1977).

Spawning continued through the early part of June with eggs being collected in very small numbers further upriver through early July, attributable to a few late spawners.

The period of peak egg abundance for 1982 and previous years occurred when the water reached an average temperature of 15°C and conductivity of 0.14 mS/cm (0.3 °/oo). This time is usually centered around the third week of May (Table 4.1-1).

4.1.2 Yolk-Sac Larvae

Striped bass yolk-sac larval densities at the beginning of sampling were greater than 10/1000 m^3 in the middle estuary. The peak abundance of the yolk-sac larvae occurred during the same sampling week as peak egg abundance, largely due to a steady rise in water temperature (13°-17°C) which decreased hatching to yolk absorption duration from 10 days to 7 days. Yolk-sac larvae were collected throughout June with densities ranging from 10-100/1000 m^3 at temperatures of 18°-22°C, after which transformation to the post yolk-sac stage was complete for most of the larvae. In prior years, the peak period of yolk-sac abundance had also been between the third week of May and first week of June when water temperature averaged 16-20°C (Table 4.1-2).

In 1982, the area of yolk-sac peak abundance appeared to be upriver from the area of peak egg deposition (Figure 4.1-3). This was also observed in previous years (TI, 1981; Battelle, 1983) as well as in other estuarine systems (Setzler-Hamilton *et al.*, 1981). The region of peak abundance in 1982 was Poughkeepsie, where mean water temperature was 18°C and mean conductivity was 0.137 mS/cm (Appendix C, Table C-5).

TABLE 4.1-1. MEAN TEMPERATURE (°C) AND CONDUCTIVITY (mS/cm) DURING THE PERIODS OF STRIPED BASS EGG ABUNDANCE IN THE MIDDLE ESTUARY[b], INDIAN POINT, WEST POINT, AND POUGHKEEPSIE, HUDSON RIVER ESTUARY, 1974-1982.

YEAR	PEAK PERIOD	TEMPERATURE - °C MEAN	TEMPERATURE - °C RANGE	CONDUCTIVITY - (mS/cm) MEAN	CONDUCTIVITY - (mS/cm) RANGE
1974	12 May-25 May	15.4	13.0-16.5	0.164	0.155-0.176
1975	18 May-31 May	19.0	17.9-22.0	0.137	0.114-0.178
1976	23 May-05 Jun	15.0	13.0-17.0	0.152	0.139-0.176
1977	15 May-28 May	14.6	12.0-17.0	0.147	0.126-0.218
1978	21 May-27 May	15.7	15.0-17.0	0.162	0.141-0.253
1979	06 May-19 May	16.2	12.5-19.5	0.192	0.110-2.000
1980	19 May-22 May	16.3	15.4-16.8	0.242	0.169-0.383
1981	18 May-21 May	15.9	15.8-16.1	0.208	0.180-0.237
1982	24 May-28 May	17.1[a]	17.0-17.4	0.340[a]	0.144-0.729

[a] These values are the mean of the West Point, Poughkeepsie, and Hyde Park regions.

[b] Sources: TI, 1981 (1974-1979); Battelle, 1983 (1980-1981).

TABLE 4.1-2. MEAN TEMPERATURE (°C) AND CONDUCTIVITY (mS/cm) DURING THE PERIODS OF STRIPED BASS YOLK-SAC LARVAE ABUNDANCE IN THE MIDDLE ESTUARY[b], INDIAN POINT, WEST POINT, AND POUGHKEEPSIE, HUDSON RIVER ESTUARY, 1974-1982.

		TEMPERATURE - °C		CONDUCTIVITY - (mS/cm)	
YEAR	PEAK PERIOD	MEAN	RANGE	MEAN	RANGE
1974	26 May-08 Jun	17.5	16.2-19.0	0.175	0.136-0.312
1975	25 May-07 Jun	19.9	18.2-22.0	0.158	0.010-0.884
1976	30 May-12 Jun	16.4	14.5-19.0	0.155	0.142-0.220
1977	22 May-04 Jun	17.0	14.5-21.0	0.162	0.135-0.221
1978	28 May-10 Jun	20.2	19.0-21.8	0.152	0.095-0.282
1979	20 May-02 Jun	18.2	14.5-22.0	0.173	0.120-1.550
1980	27 May-30 May	17.2[a]	16.3-17.7	0.176[a]	0.173-0.180
1981	18 May-21 May	15.9	15.8-16.1	0.208	0.180-0.237
1982	24 May-28 May	17.1[a]	17.0-17.4	0.340[a]	0.144-0.729

[a] These values are the mean of the West Point, Poughkeepsie, and Hyde Park regions.
[b] Sources: TI, 1981 (1974-1979); Battelle, 1983 (1980-1981).

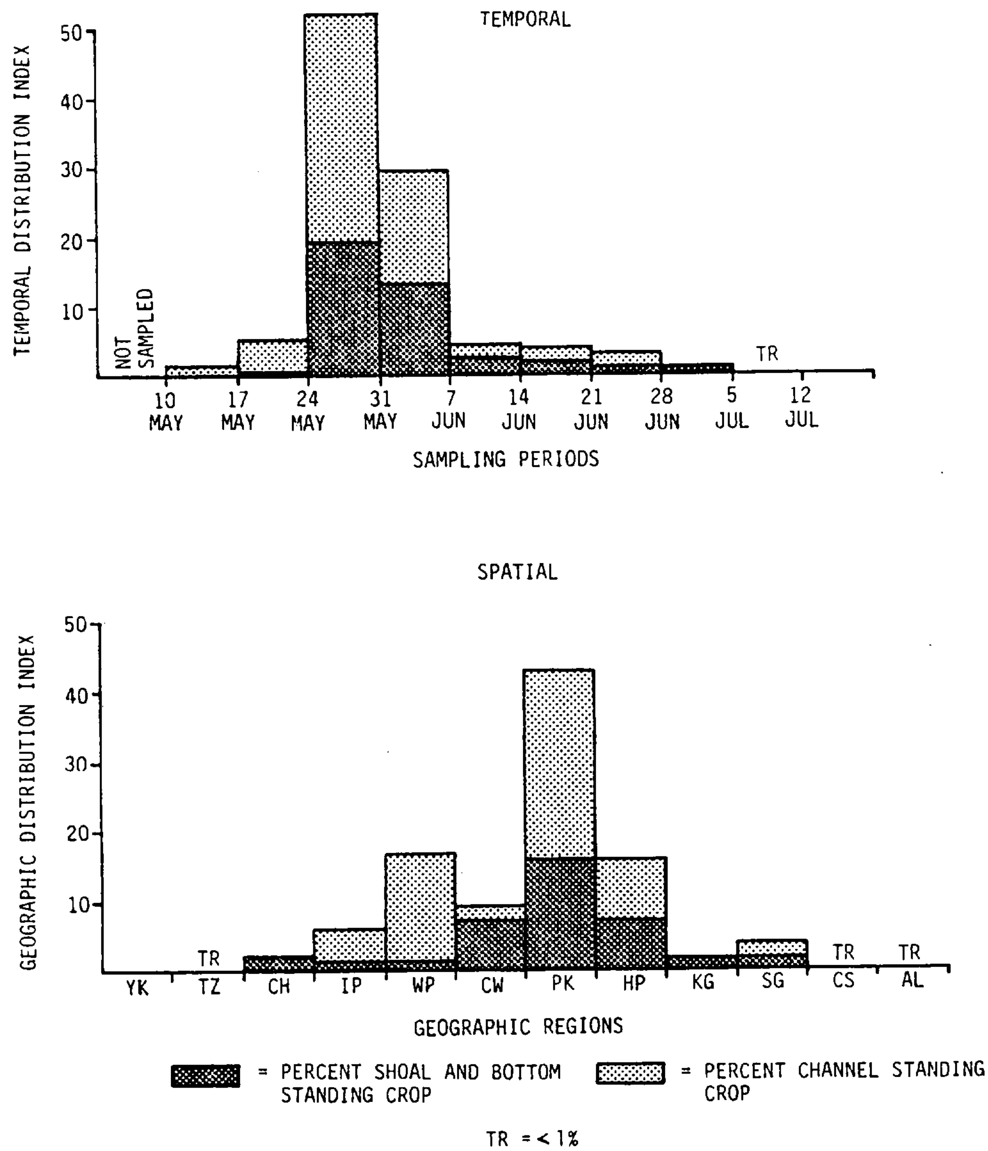


Figure 4.1-3. Patterns in distribution of striped bass yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

At the start of the 1982 sampling, yolk-sac abundance appeared to be in the Croton-Haverstraw to West Point regions (Figure 4.1-4), but a weekly shift northward was observed with the final area of concentration being in the Poughkeepsie and Hyde Park regions during the week of 31 May. This appears, as with eggs, to be in relation to the movement of the salt front (0.3 mS/cm). When conductivities increased above 1.0 mS/cm in the initial area of concentration, yolk-sac abundance shifted upriver to areas where conductivity remained below 0.3 mS/cm. During yolk-sac abundance, temperatures remained at approximately 18^{o}C, where duration of this stage would be six days. This temperature appears to be optimum for development (Morgan and Rasin, 1981). Peak abundance of yolk-sac larvae from 1974 to 1982 occurred when water temperature reached a mean of 16-20^{o}C and a conductivity of 0.16 to 0.34 mS/cm (Table 4.1-2).

Yolk-sac larvae are believed to be positively phototaxic tending to concentrate closer to the bottom as feeding begins (Hardy, 1978). This change in depth distribution has also been observed in the Hudson River estuary (Rathjen and Miller, 1957) and in Chesapeake Bay and the Delaware River (Kernehan *et al.*, 1981) to occur approximately one week after hatching. McFadden *et al.* (1978) observed striped bass yolk-sac larvae to be more concentrated in bottom waters during the day and in surface waters at night in the Cornwall area of the Hudson. In 1982 these observations of increasing bottom densities and diel differences in vertical distribution were supported by the relative densities in the channel and bottom strata. At first the larvae were approximately equally concentrated in the two strata. Then by late May or early June the yolk-sac larvae were observed in higher densities in the bottom stratum than in the channel stratum. In the week of 14 June, when nighttime sampling began, channel densities were again comparable to those of the bottom. This increase in channel to bottom density ratio associated with night sampling was probably due, at least in part, to daytime gear avoidance in near-surface waters.

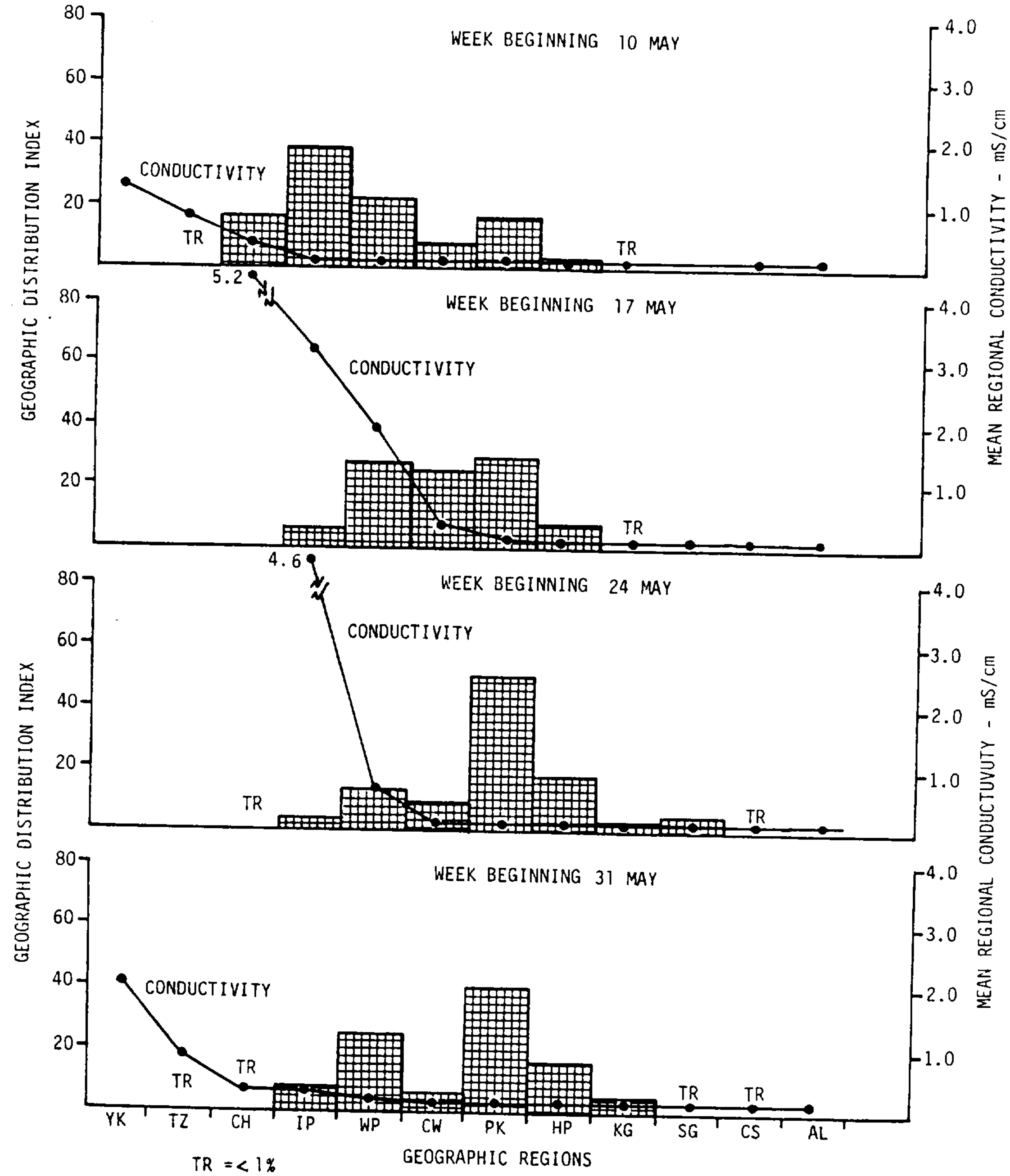


Figure 4.1-4. Weekly geographic distribution of striped bass yolk-sac larvae during the period of peak abundance and its relationship to conductivity, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

4.1.3 Post Yolk-Sac Larvae

During the time of peak larval abundance, mean water temperature was 18°C. At this temperature Rogers *et al.* (1977) estimated that the duration of the yolk-sac stage would be 6-7 days. Abundance of striped bass post yolk-sac larvae peaked during the first week of June, one week after the peak abundance of yolk-sac larvae occurred. Post yolk-sac larvae continued to be taken throughout the remainder of the season, but in reduced numbers after the second week of June. The average duration of the post yolk-sac stage is 30-33 days at 18°C (Rogers *et al.*, 1977). Since temperatures at this time were 18-19°C and only two weeks had transpired since yolk absorption, the observed reduction in post yolk-sac larvae is primarily due to increased mortality during the early larval stage and to gear avoidance (Kernehan *et al.*, 1981).

The regions of peak post yolk-sac abundance were centered in the middle estuary and upper part of the lower estuary (Figure 4.1-5). Early post yolk-sac larvae were most concentrated in the Poughkeepsie region, with equal distribution in the water column (Figure 4.1-6). As swimming ability increased, older post yolk-sac larvae were taken in higher numbers further downstream and in the bottom stratum. This downriver shift can be attributed to a variety of factors, including higher survival of this stage in more saline waters, passive transport downstream (TI, 1981) and the movement downstream with food items, e.g. *Gammarus* spp. (Rathjen and Miller, 1957). The transport explanation can be supported by freshwater flow patterns in 1982. An increase of freshwater flow (13,000 to 41,000 ft^3/s) in early June, during the period of peak abundance, could have displaced a large portion of the post yolk-sac larvae downriver. It appears, as noted in previous year class reports, that there is a general tendency for dispersal downriver and towards the bottom as feeding begins. This is supported by the fact that post yolk-sac larvae were taken in a wide range of temperatures (14.5°-23.5°C) and conductivities (0.070-5.217 mS/cm) (Table 4.1-3).

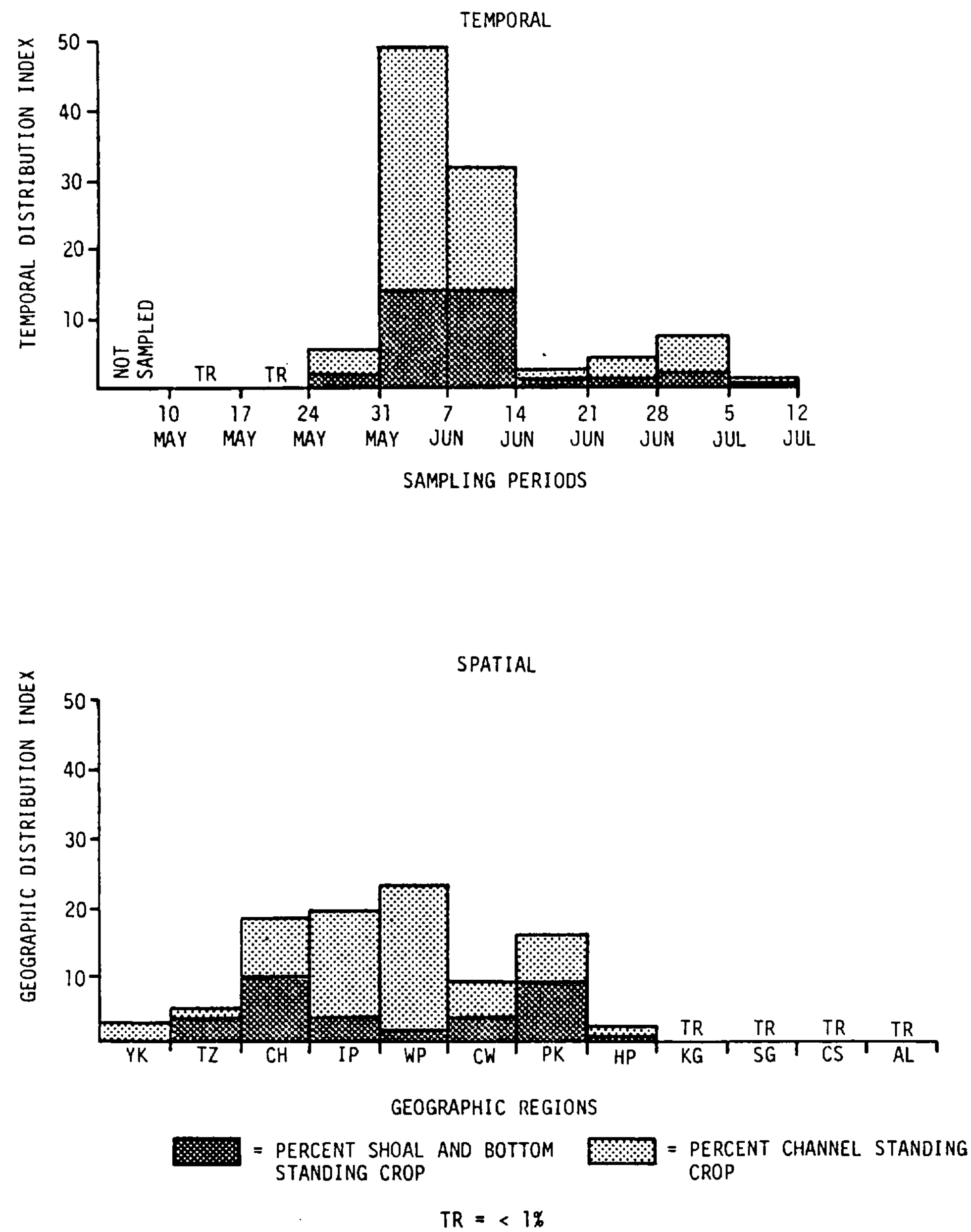


Figure 4.1-5. Patterns in distribution of striped bass post yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

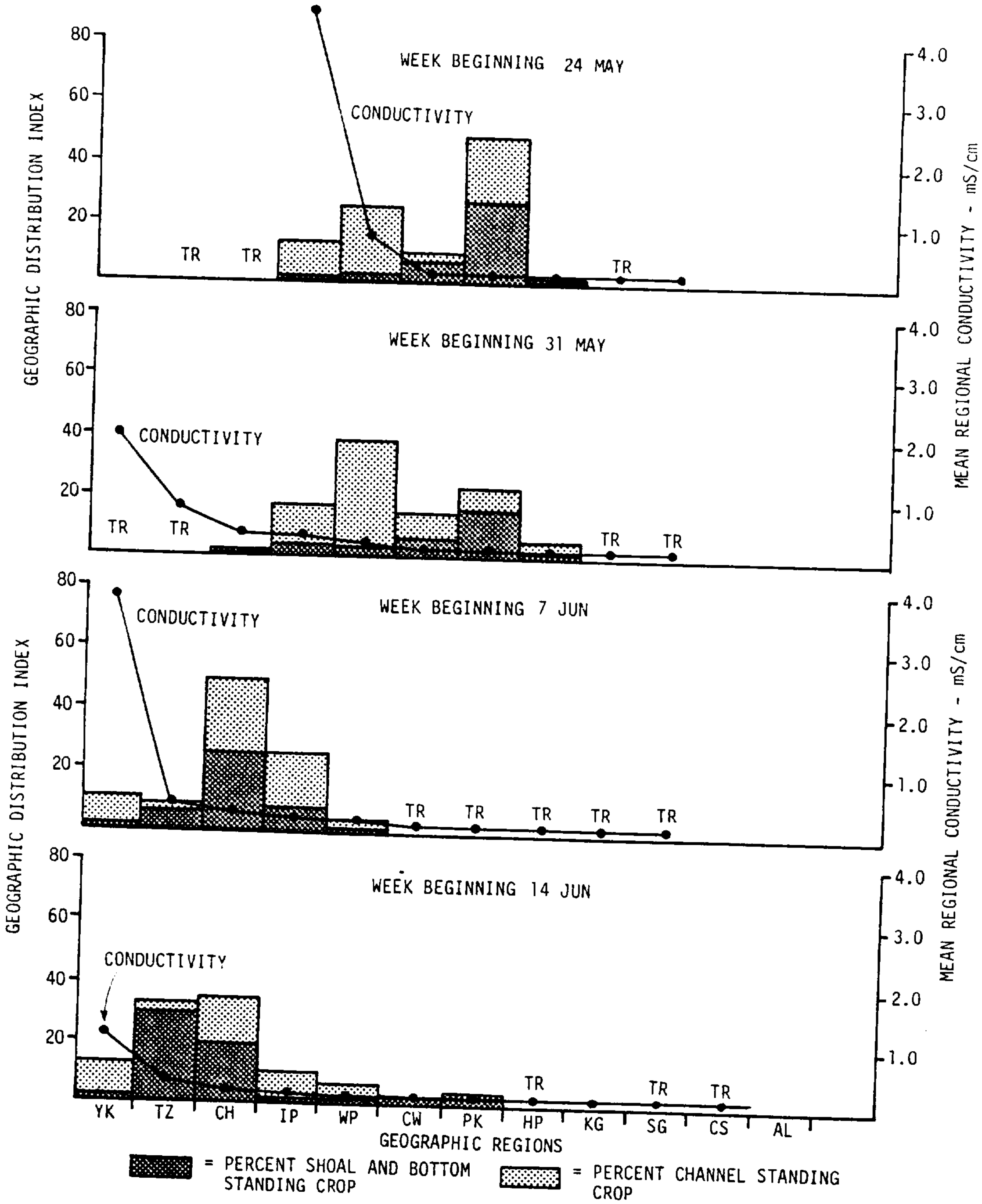


Figure 4.1-6. Weekly geographic distribution of striped bass post yolk-sac larvae during the period of peak abundance and its relationship to conductivity, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

TABLE 4.1-3. MEAN TEMPERATURE (°C) AND CONDUCTIVITY (mS/cm) DURING THE PERIODS OF STRIPED BASS POST YOLK-SAC LARVAE ABUNDANCE IN THE MIDDLE ESTUARY[b], INDIAN POINT, WEST POINT, AND POUGHKEEPSIE, HUDSON RIVER ESTUARY, 1974-1982.

		TEMPERATURE - (°C)		CONDUCTIVITY - (mS/cm)	
YEAR	PEAK PERIOD	MEAN	RANGE	MEAN	RANGE
1974	09 Jun-22 Jun	21.5	19.9-23.5	1.032	0.125-3.351
1975	01 Jun-14 Jun	20.6	19.5-22.0	0.579	0.070-4.808
1976	06 Jun-19 Jun	18.6	16.0-22.0	0.154	0.144-0.221
1977	29 May-18 Jun	19.3	17.5-21.2	0.770	0.138-5.217
1978	04 Jun-17 Jun	20.7	19.5-23.1	0.162	0.095-0.282
1979	27 May-02 Jun	18.4	14.5-22.0	0.155	0.125-0.245
1980	02 Jun-13 Jun	18.2	17.5-19.0	1.600	0.400-4.500
1981	01 Jun-13 Jun	18.0	17.0-19.0	1.300	1.000-1.600
1982	31 May-09 Jun	18.5[a]	17.9-18.9	0.267[a]	0.159-0.477

[a] These values include Croton-Haverstraw.

[b] Sources: TI, 1981 (1974-1979); Battelle, 1983 (1980-1981).

4.1.4 Young-of-the-Year

Transformation of post yolk-sac larvae to juveniles had begun by the week of 28 June, during the ichthyoplankton sampling (Figure 4.1-7). Temperatures at this time averaged 22^{o}C with conductivities averaging 5 mS/cm in the lower estuary. The juvenile abundance at the time of transformation was observed to be concentrated in the upper reaches of the lower estuary where conductivities were higher than those previously encountered during the post yolk-sac stage. Rathjen and Miller (1957) noted that those specimens making their way downriver to higher salinities tended to increase in length faster than those captured upriver in freshwater.

Peak abundance of early juveniles in the offshore strata (channel, bottom, and shoals) occurred during the month of July (Figure 4.1-7) through the early part of August (Figure 4.1-8). The juveniles had begun moving into the shore zone by the middle of August (Figure 4.1-9), with abundance reaching its peak at the end of September, while densities were decreasing in the offshore strata. In general, juvenile striped bass tend to be more abundant in those locations with a sand or gravel bottom and a pronounced current (Rathjen and Miller, 1957 Hardy, 1978).

The general pattern of juvenile distribution in the offshore strata suggests that dispersion of striped bass from the study area began in late August and continued through September as the increase in the shore zone abundance was less than the decrease in the offshore strata. It appears that emigration for those juveniles leaving in early August was by way of the deeper offshore strata. Those remaining until the end of fall and/or those overwintering in the estuary, tended to move into the shore zone of the lower estuary.

Shore zone conductivities in the lower estuary area were approximately 12 mS/cm from mid-August to early September (Figure 3.1-2). Juvenile abundance in the shore zone remained relatively constant throughout August, increasing slightly in September and then

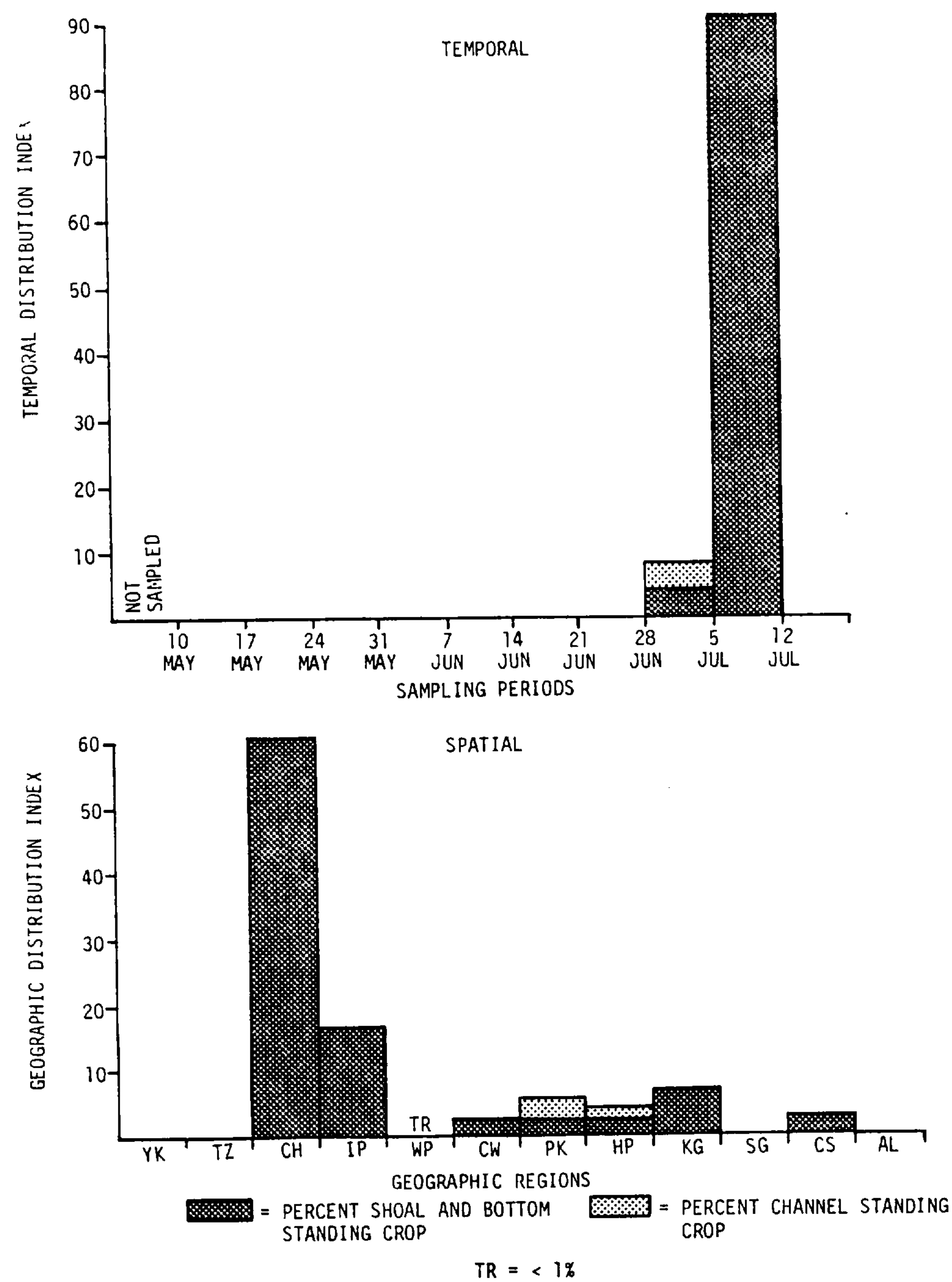


Figure 4.1-7. Patterns in distribution of striped bass young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

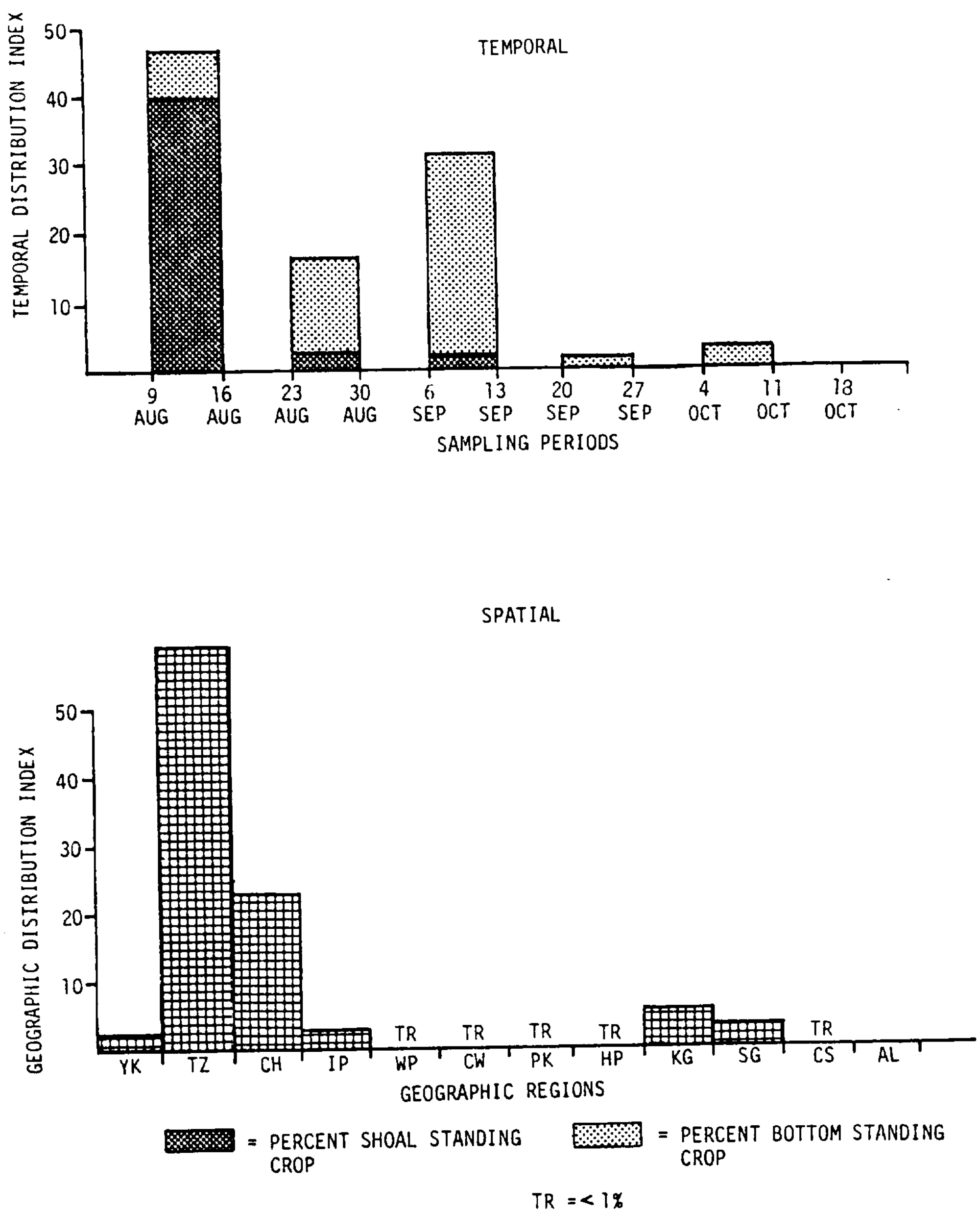
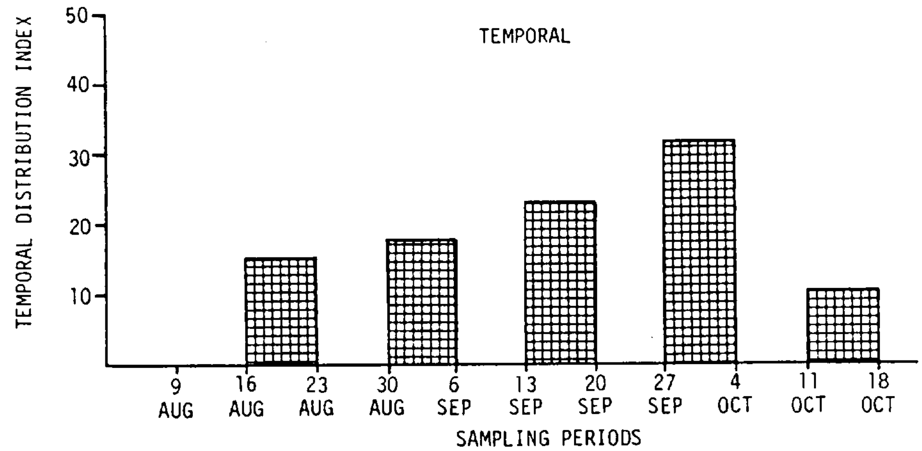


Figure 4.1-8. Patterns in distribution of striped bass young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals sampling).



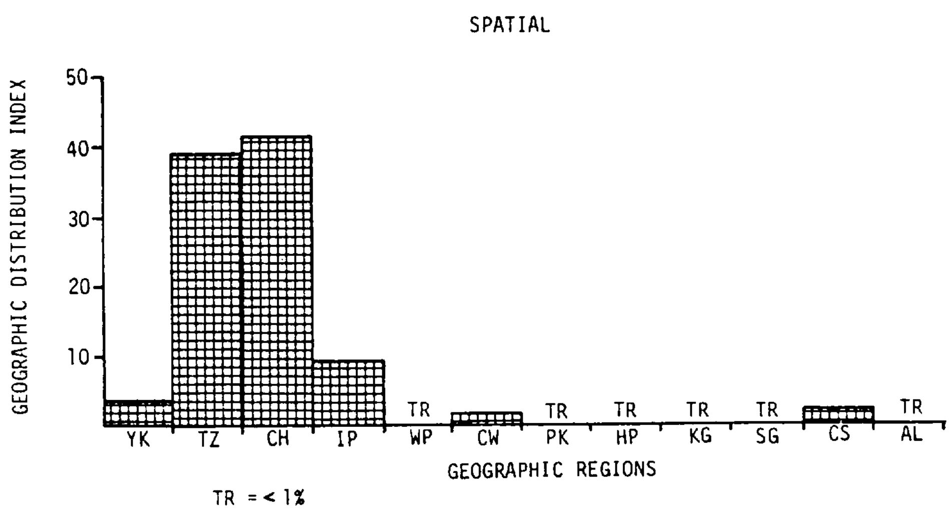


Figure 4.1-9. Patterns in distribution of striped bass young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine sampling).

decreasing in October as the young striped bass in the shore zone began to disperse downriver from the middle and upper estuary, accumulating in the lower estuary prior to and during their seaward migration. Most of the juvenile striped bass appear to move out of the estuary during the fall; however some fish presumably do remain in the deeper parts of the lower estuary to overwinter (McFadden *et al.*, 1978; McLaren *et al.*, 1981; TI, 1981).

4.1.5 Yearling and Older Fish

Yearling striped bass (members of the 1981 year class) were already being taken when Fall Shoals and Beach Seine sampling began in August. Most of these fish were taken in the shore zone throughout the entire estuary (Figure 4.1-10 and Figure 4.1-11). Peak abundance of striped bass yearlings occurred in the early part of September, decreasing after that as the fish started their seaward migration.

Older striped bass were taken most frequently in the offshore strata (Figure 4.1-10). These fish were taken between Yonkers and Catskill with the greatest concentration in the lower estuary within the bottom stratum.

4.2 WHITE PERCH

The white perch, *Morone americana* (Gmelin), is a common resident species in estuaries along the Atlantic coast from Nova Scotia to South Carolina (Bigelow and Schroeder, 1953; Scott and Crossman, 1973). It has been introduced into freshwater systems along the Atlantic coastal plain and has become established in the Great Lakes (Mansueti, 1961; Scott and Christie, 1963; Hardy, 1978). The distribution of white perch in the Hudson River extends from the Battery at Manhattan (RM 0) north to the Troy Dam at Albany N.Y. (RM 152) (TI, 1981). A euryhaline species, white perch are found in waters with

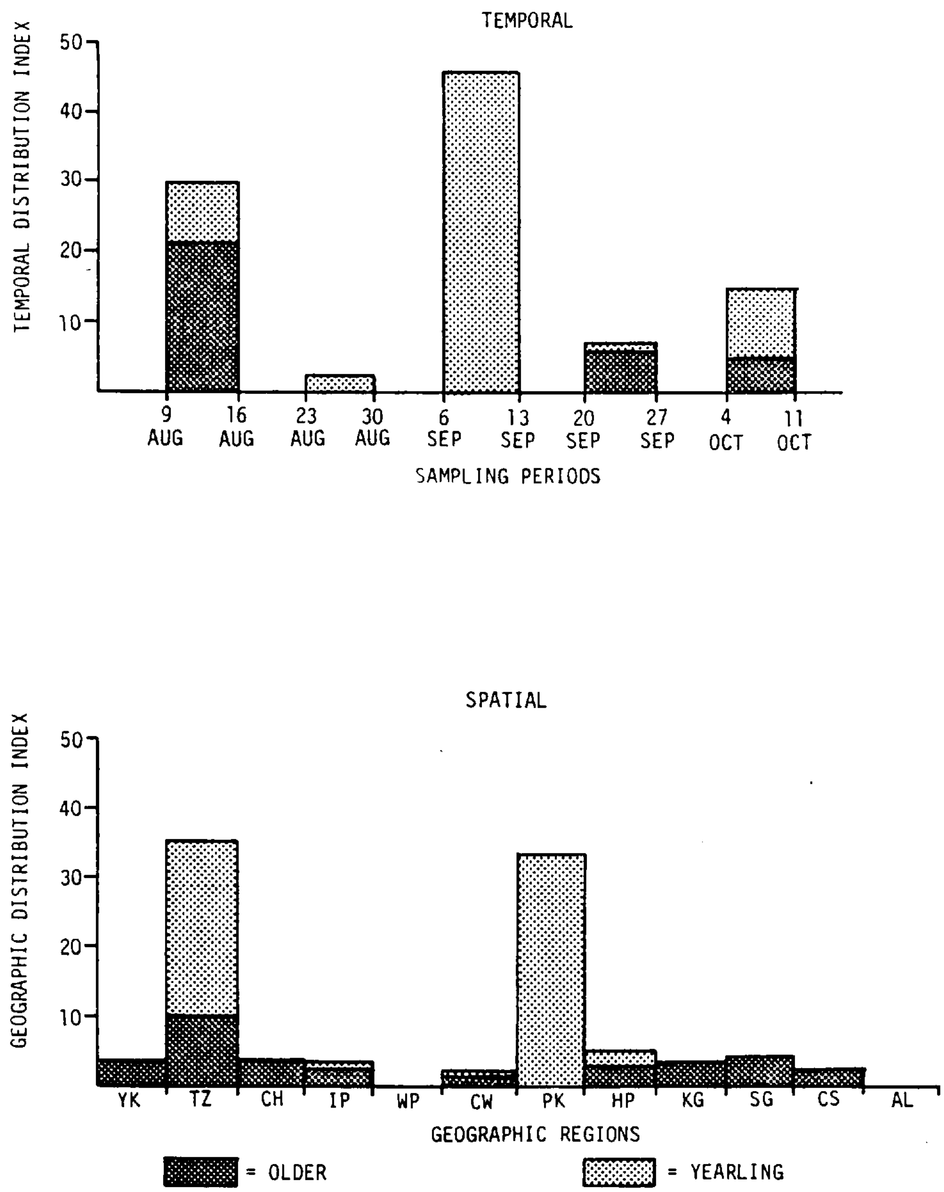


Figure 4.1-10. Patterns in distribution of striped bass yearling and older, Hudson River estuary, 1982 (based on Fall Shoals sampling).

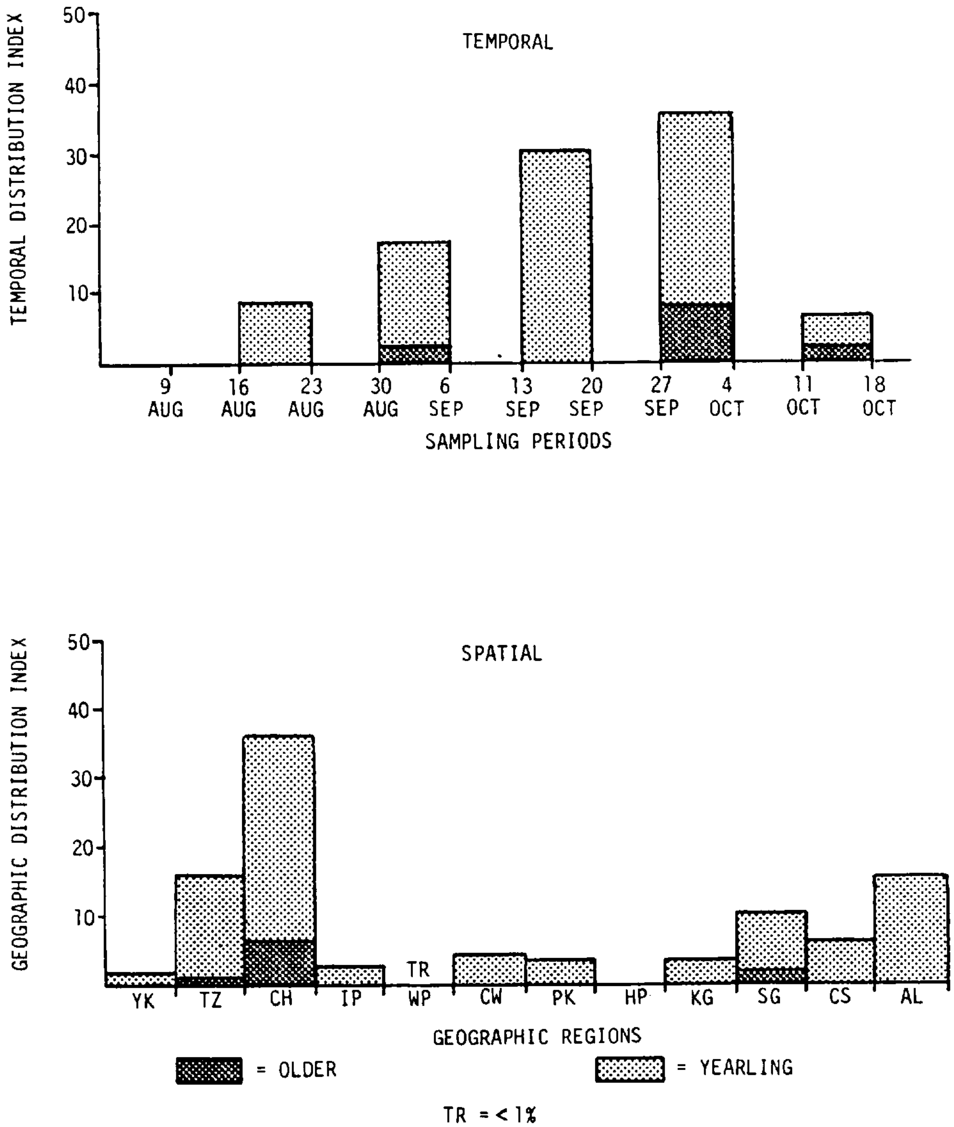


Figure 4.1-11. Patterns in distribution of striped bass yearling and older, Hudson River estuary, 1982 (based on Beach Seine sampling).

salinity concentrations ranging from 0 to 30 ^{o}/oo but are most common in brackish water locations.

The white perch is semi-anadromous and occasionally undergoes extensive spawning migrations within estuarine systems (Mansueti, 1961). The extent of spawning migrations is related to the proximity of over-wintering and spawning grounds (Klauda *et al.*, in review). In the Hudson River estuary, white perch overwinter in the deep offshore areas of the river particularly in the lower and middle estuary (TI, 1981). During spring, they move upriver and shoreward. Most of the suitable spawning habitat is in the upper estuary and it is here that peak spawning usually occurs and that eggs and larvae are concentrated. Spawning generally takes place in freshwater but may occur in salinities up to 2 ^{o}/oo (Mansueti, 1961; Lippson *et al.*, 1980; TI, 1981). Following the spring spawning run there is a gradual downriver movement followed by an offshore movement during fall. Although white perch are semi-anadromous, they generally do not leave their natal estuary (Mansueti, 1961). In addition, they are indigenous to particular estuarine systems and exhibit little mixing with white perch populations in other regions.

Larval and juvenile white perch feed on rotifers, copepods, cladocerans and insects. Adults are largely non-specific rapacious feeders and consume a wide variety of prey types (Loos, 1975). In turn, white perch are prey for striped bass, bluefish and larger white perch. No major commercial fishery exists for white perch in the Hudson River (McHugh and Ginter, 1978); however, they are an important commercial species in other locations such as the Chesapeake Bay (Mansueti, 1961; Lippson *et al.*, 1980).

4.2.1 Eggs

White perch eggs are demersal and adhesive, thus they are relatively invulnerable to ichthyoplankton sampling gear. Eggs sampled by this program are those which have become dislodged and are free-floating. Therefore, data collected on white perch eggs by ichthyoplankton sampling may not provide a totally realistic representation of the magnitude or spatiotemporal distribution of white perch egg deposition in the estuary. Only if the ratio of dislodged eggs to attached eggs is consistent spatially and temporally can the occurrence of dislodged eggs provide information on spatiotemporal trends in spawning. During 1982, there was a reasonably high correlation ($r = 0.88$, $p < 0.05$) of egg standing crop to freshwater flows (Table 4.2-1). Based on this information, the number of dislodged eggs collected during a particular sampling period can be related, in part, to the magnitude of freshwater flows.

This correlation may suggest that increased freshwater flows stimulate spawning activity, which results in a proportional increase in the number of free-floating eggs. No data are available, however, to substantiate this position. Increases in water temperature combined with low salinity are important factors that influence spawning and egg development (Morgan and Rasin, 1982). While high freshwater flows may reduce salinity, these events resulted in declines in temperatures which should have inhibited spawning activity (Figure 4.2-1). Alternatively, the ratio of dislodged eggs to attached eggs may increase with increasing flows due to a greater degree of physical disturbance. Given a constant number of attached eggs, fluctuations in freshwater flow and the resulting physical disturbance may produce fluctuations in the proportion of eggs that are dislodged from the bottom. Thus, seasonal and annual trends in egg standing crop as estimated by ichthyoplankton sampling may be biased by seasonal variations in freshwater flow. Because egg abundance was positively correlated with freshwater flow this study does not make the assumption used in past year class reports that temporal trends in free-floating eggs realistically represent temporal trends in spawning.

During 1982, white perch eggs were present when sampling began on 10 May (Figure 4.2-1). Two pulses in egg abundance were detected: one on the first period sampled and a larger pulse during the second week of June. Both pulses corresponded to periods of high freshwater

TABLE 4.2-1. RELATIONSHIP OF FRESHWATER FLOW AT TIME OF SAMPLING TO WHITE PERCH EGG ABUNDANCE AS ESTIMATED BY ICHTHYOPLANKTON COLLECTIONS IN THE HUDSON RIVER ESTUARY, 1982.

WEEK BEGINNING MONDAY	EGG STANDING CROP (Millions)	MEAN FRESHWATER FLOW (ft^3/sec)
10 May	1034	11,160
17 May	457	7,403
24 May	537	11,860
31 May	248	12,557
7 Jun	2331	31,633
14 Jun	159	12,925

correlation coefficient = 0.88, $p < 0.05$

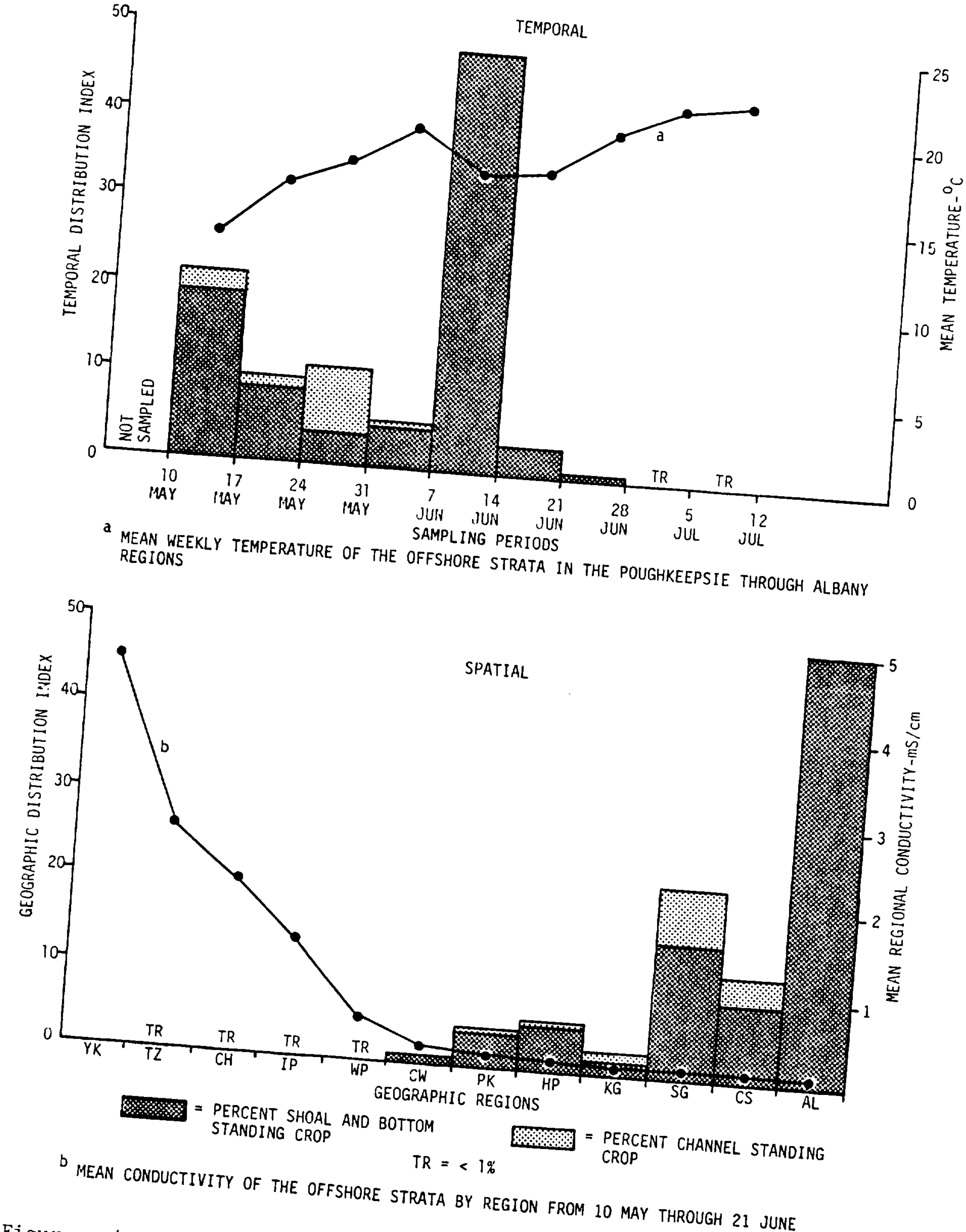


Figure 4.2-1. Patterns in distribution of white perch eggs, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

flows, particularly the second pulse (Table 4.2-1), and consequently may not represent peak spawning. If trends in larval abundance presented in Sections 4.2.2 and 4.2.3 reflect successful spawning activity, then the first pulse most closely approximated the time of peak successful spawning. White perch egg standing crop decreased considerably after the second pulse on 7 June and reached trace levels by the 28 June sampling period. Peak egg abundance in past years has been reported for the first week of May through the second week of June. Based on yolk-sac larva abundances, peak successful spawning occurred during mid-May in most years. During 1982, white perch eggs were concentrated in the Poughkeepsie through Albany regions (98.2% of standing crop) which had mean conductivity values less than 0.5 mS/cm. Eggs were present as far downriver as Tappan Zee (mean conductivity = 2.7 mS/cm) but only in trace concentrations. This spatial distribution was similar to the general pattern described for white perch in the past. As expected egg abundances were highest in the bottom and shoal strata (90% of egg standing crop).

Mean water temperature in the regions of peak abundance during the 10 May - 7 June sampling periods ranged from 13.0 to 19.5°C (Appendix C, Table C-1). This is similar to previous observations that spawning generally begins as water temperatures reach 14°C and peaks between 16 and 20°C (Hardy, 1978). Klauda *et al.* (in review) also reported peak egg deposition at 16-20°C to occur in the upper segment of the Hudson River estuary. During 1982, peak successful spawning occurred at approximately 13°C.

4.2.2 Yolk-Sac Larvae

The abundance of yolk-sac larvae may more accurately reflect the spatiotemporal distribution of egg deposition than free-floating eggs. They are more vulnerable than eggs to this program's sampling gear, they exhibit only limited mobility, and they have a relatively short life stage duration (3-5 days; Mansueti, 1964). Like white perch eggs, yolk-sac larvae were present when sampling began the week of 10

May (Figure 4.2-2). The largest proportion of yolk-sac larva standing crop occurred the following week at a mean temperature of 16°C. This is consistent with the optimal temperature for hatching (14.1°C) determined experimentally by Morgan and Rasin (1982). Following this peak, abundance of yolk-sac larvae steadily declined to trace levels during the last two weeks of the survey. This pattern in yolk-sac larva standing crop suggests that peak egg deposition occurred in 1982 during mid-May. In addition, no peak in yolk-sac larva standing crop was found to coincide with or follow the primary egg peak during the week of 7 June. This further supports the supposition that the peak in water-born egg abundance during that week was due to an increase in the proportion of dislodged eggs resulting from heavy river flow rates rather than to a pulse in egg deposition. Abundance of yolk-sac larvae during 1974-1981 most often peaked during the third or fourth week of May at average temperatures of 16-21°C (TI, 1981, Battelle, 1983). The temporal pattern of yolk-sac larva standing crop observed in 1982 was similar to the patterns recorded for past years.

The spatial distribution of yolk-sac larvae was similar to that of eggs. Larvae were largely concentrated in the Poughkeepsie through Albany regions; a small proportion of the larvae extended downriver to Yonkers. As with eggs, yolk-sac larvae were largely restricted to waters with conductivity values less than 0.5 mS/cm. Any extension in larval distribution downriver corresponded reasonably well with a downstream movement of the salt front (Figure 4.2-3).

4.2.3 Post Yolk-Sac Larvae

As in past years, estimated total standing crop of post yolk-sac larvae (13 billion) exceeded the estimated standing crops of both eggs (5 billion) and yolk-sac larvae (2 billion). Post yolk-sac larvae are more vulnerable to the sampling gear, due to their more pelagic nature, longer life-stage duration and larger size. Peak abundance of post yolk-sac larvae followed the peak of yolk-sac larvae by one week, and encompassed the two-week period from 24 May through 7

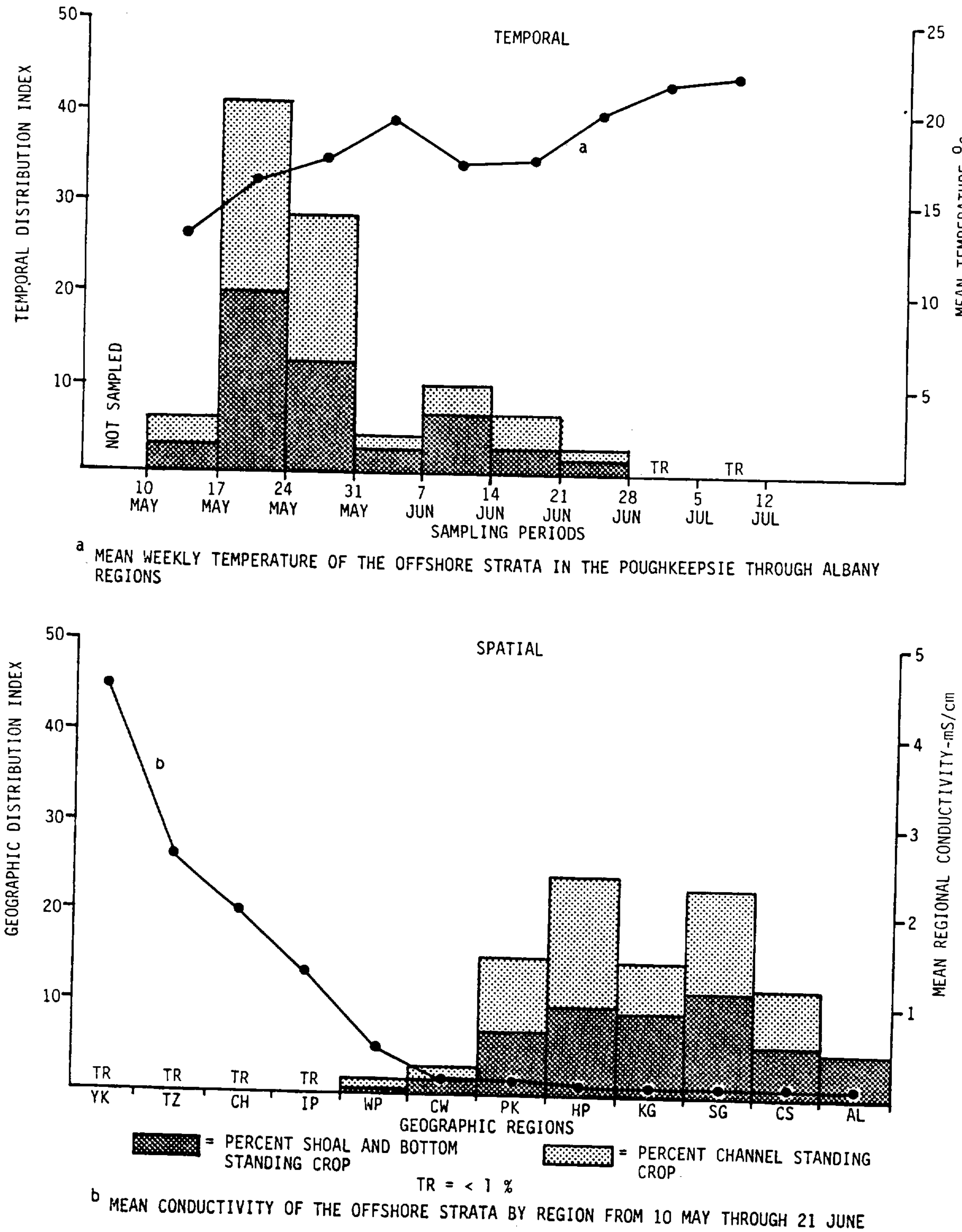


Figure 4.2-2. Patterns in distribution of white perch yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

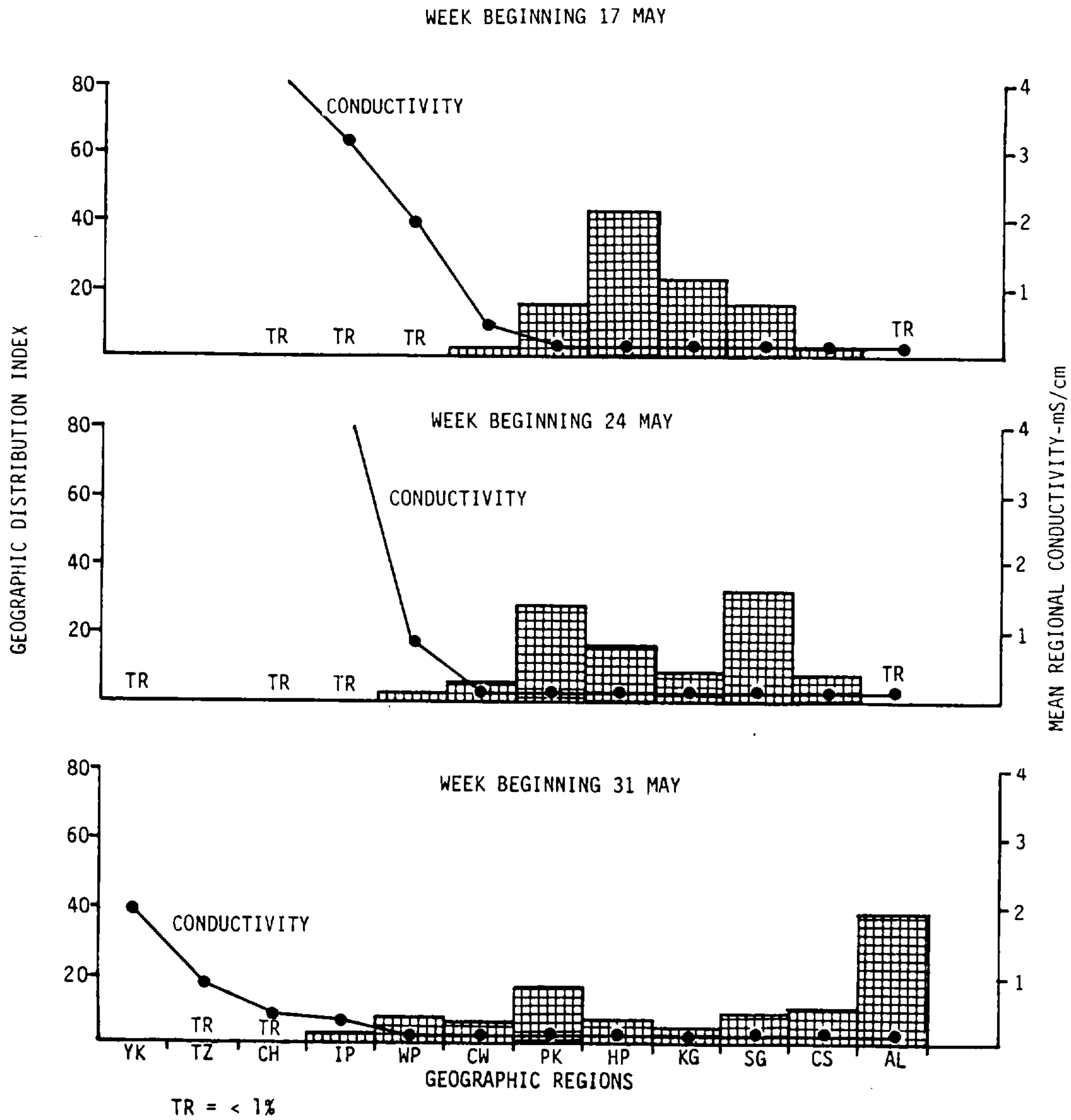


Figure 4.2-3. Weekly patterns in distribution of white perch yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

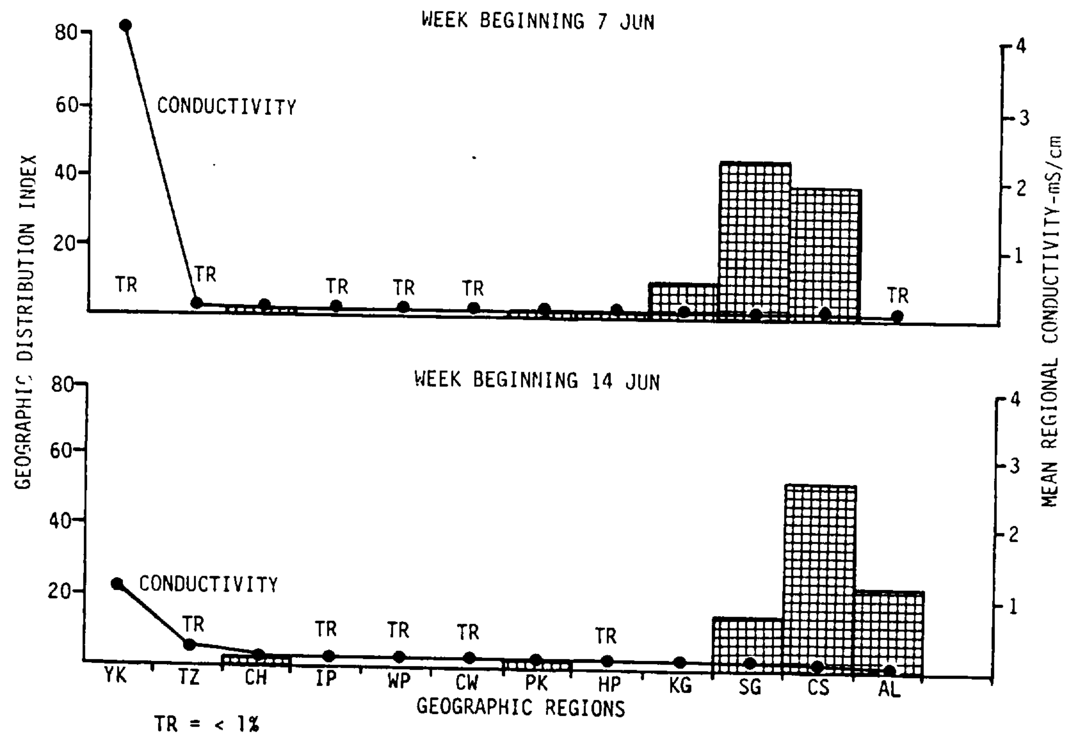


Figure 4.2-3. (Continued).

June ($\bar{x}$ temperature = 17.5-19.5^{o}C) (Figures 4.2-4 and 4.2-5). During past surveys, peaks in post yolk-sac larva abundance have commonly been detected throughout June but generally not in May. Following the late May/early June peak, standing crop declined through the last sampling period (week of 5 July) when larvae were still present in appreciable abundances.

Post-yolk sac larvae were most abundant in the Poughkeepsie region and decreased in abundance both upriver and downriver from this region (Figure 4.2-4). This distribution corresponded reasonably well with the distribution of post yolk-sac larvae observed in past surveys. Unlike eggs and yolk-sac larvae, which occurred primarily in the shoal and bottom strata, a larger proportion of post yolk-sac larvae occurred in the channel stratum. Despite this movement of larvae from the bottom and shoal into the channel, post yolk-sac larvae continued to be restricted in their seaward movement by the salt front (Figure 4.2-5). Typically, eggs and both larval stages were absent or occurred in only trace concentrations in waters with conductivity readings exceeding 0.5 mS/cm.

4.2.4 Young-of-the-Year

Juvenile white perch were first encountered during the last two sampling periods of the ichthyoplankton survey (28 June through 12 July 1982; Figure 4.2-6), approximately five weeks following the first major pulse in post yolk-sac larvae. Juvenile distribution was similar to the distribution of post yolk-sac larvae, but somewhat more concentrated in the Poughkeepsie and Hyde Park regions. Like post yolk-sac larvae, juveniles collected in the ichthyoplankton survey were most numerous in the channel. In past years, juveniles were also first encountered in late June and generally reached maximum abundance by mid-August (TI, 1981; Battelle, 1983).

Juveniles collected during the 9 August through 4 October sampling periods of the Fall Shoals survey exhibited a distribution

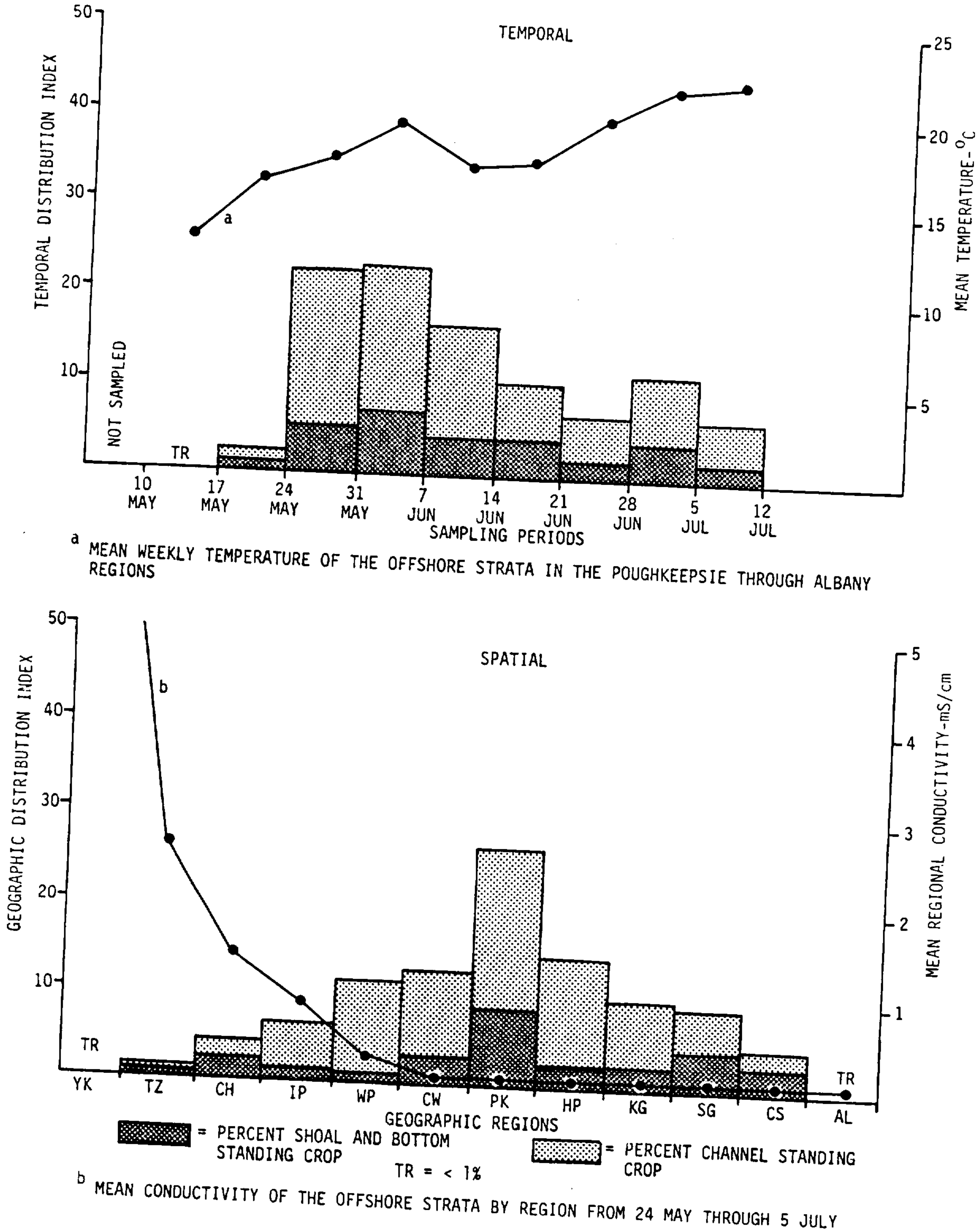


Figure 4.2-4. Patterns in distribution of white perch post yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

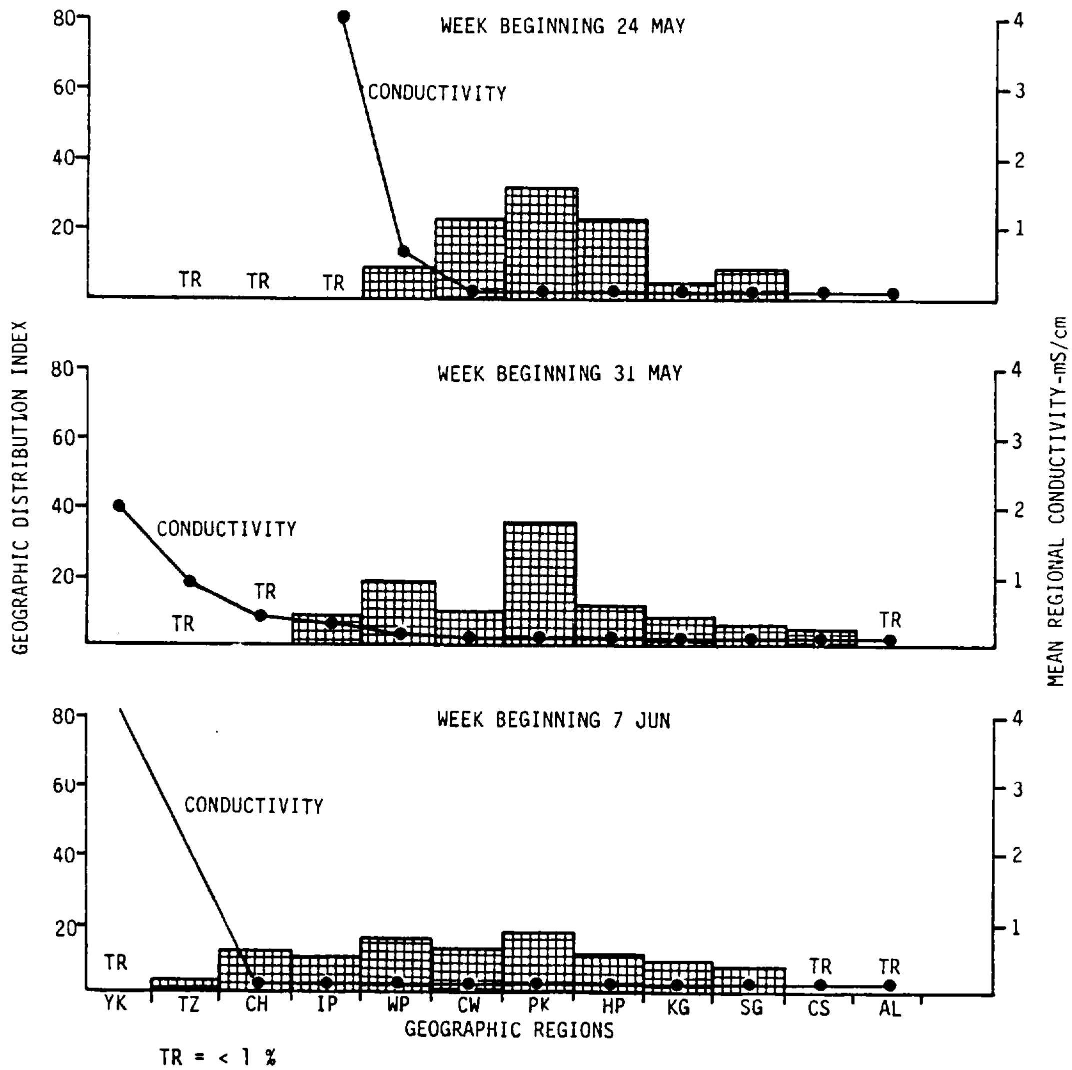


Figure 4.2-5. Weekly patterns in distribution of white perch post yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

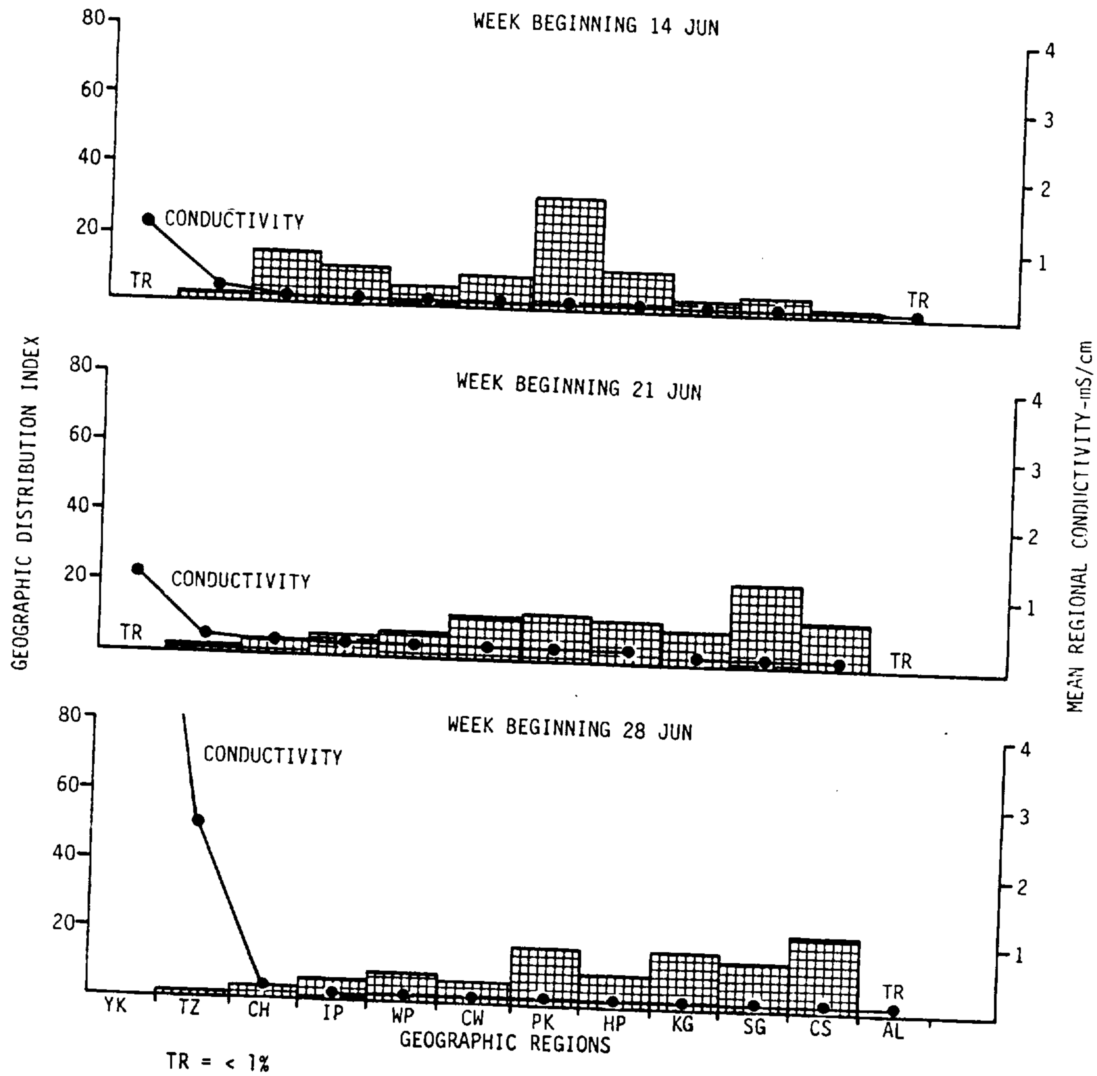


Figure 4.2-5. (Continued).

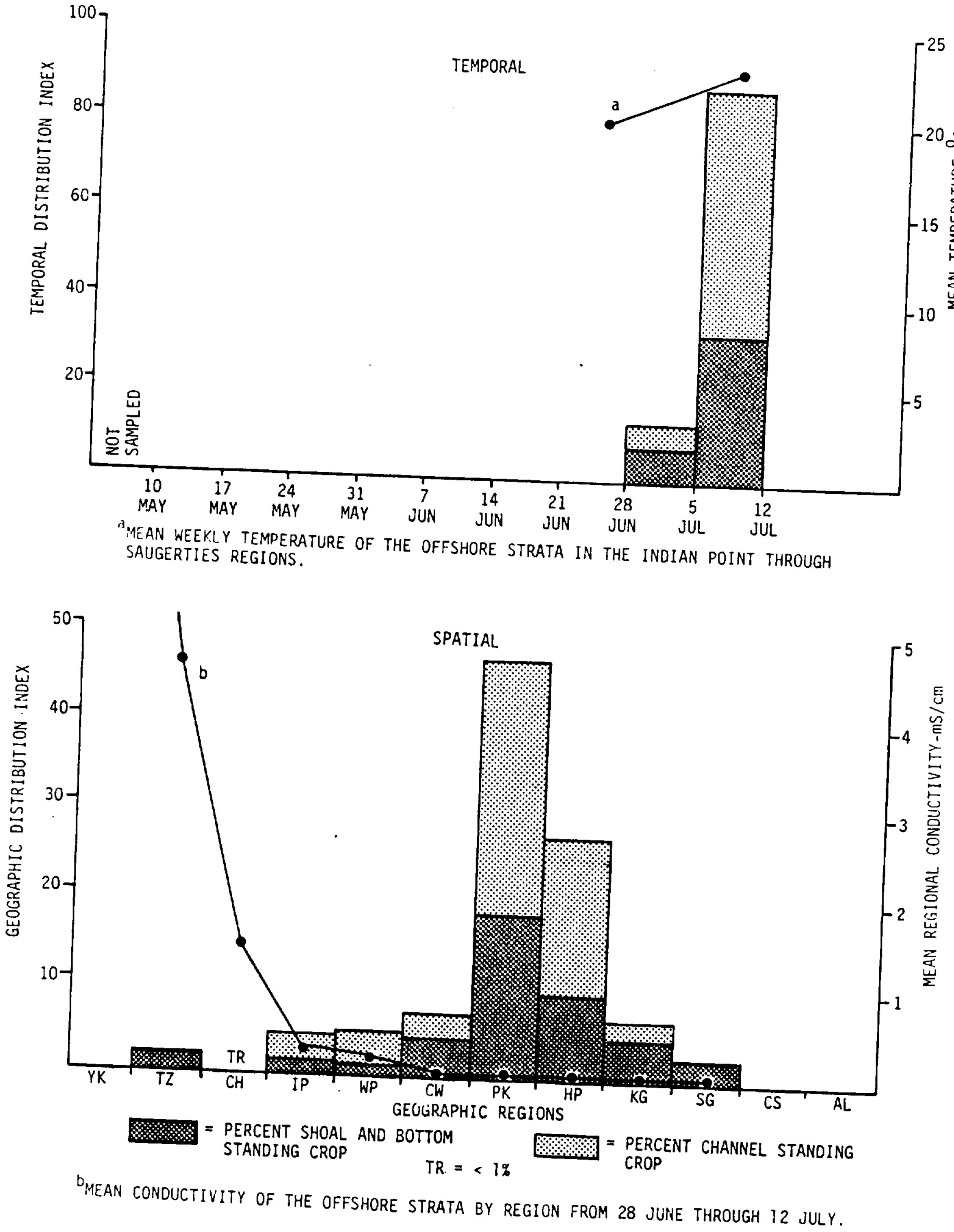
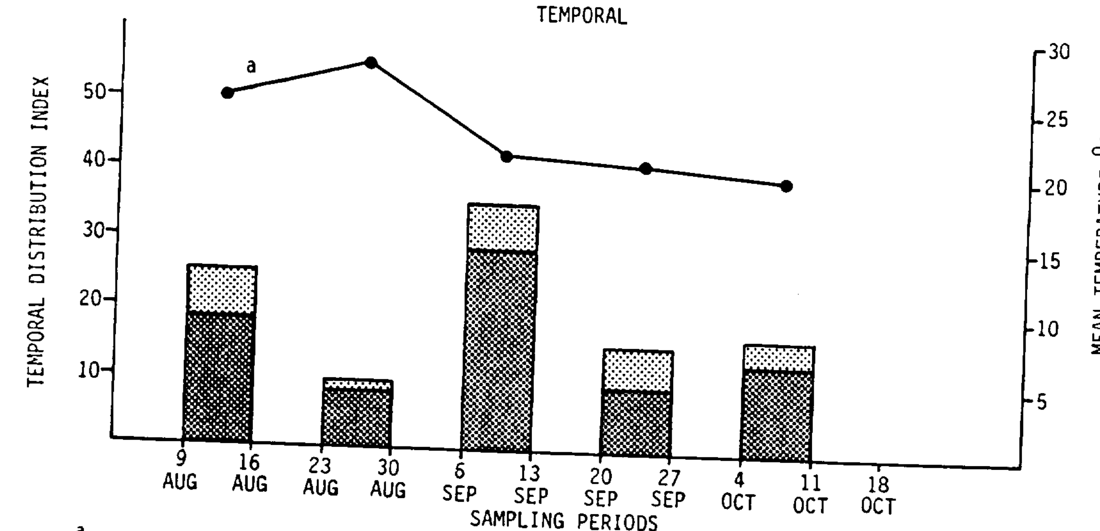


Figure 4.2-6. Patterns in distribution of white perch young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

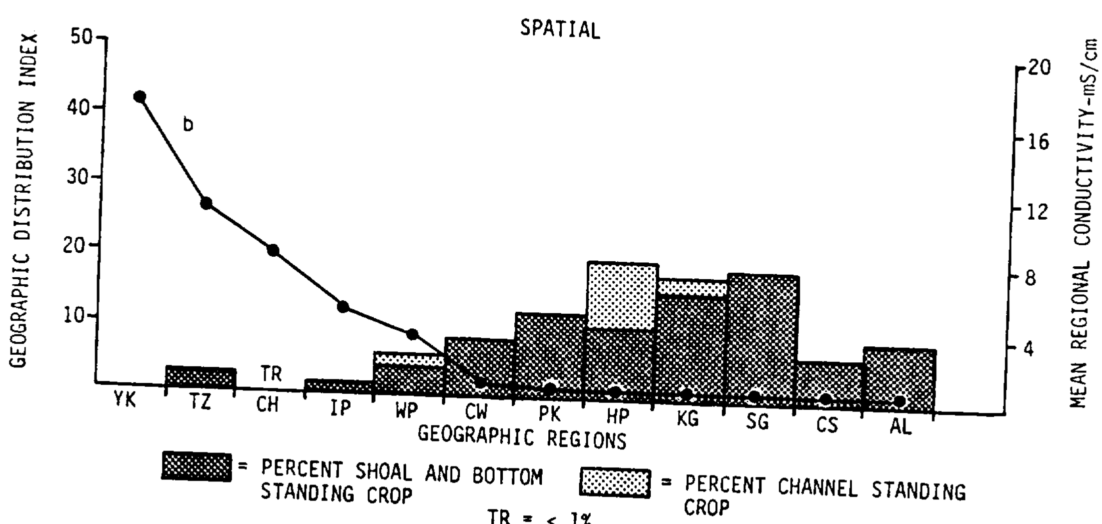
among regions that was similar to the distribution observed during the ichthyoplankton survey (Figure 4.2-7). However, by this time, distribution of juveniles within the offshore strata had shifted from the channel, back into the shoal and bottom strata. As in past years, high concentrations of white perch occurred in the shore zone of the lower estuary during late summer and fall, particularly in the Tappan Zee and Croton-Haverstraw regions (Figure 4.2-8). Based on combined standing crop data, juveniles were considerably more abundant in the shore zone during this period than in the offshore strata (Appendix B, Table B-18). This concentration of juveniles in the shore zone of the lower estuary during fall apparently reflects the downriver movement of white perch described in past years (TI, 1981). In addition, the gradual decline in shore zone standing crop recorded as fall progressed, suggests that an offshore movement into deeper waters was also occurring. In 1979, large catches of juveniles occurred in the shoal and bottom strata of the upper estuary in September and early October, and these were attributed to an emigration of juveniles from the tributaries and embayments as water temperatures declined in these regions (TI, 1981). There did not appear to be a similar peak in the upper estuary in 1982. During late October and into winter, a period that is no longer sampled by this study, white perch presumably continue their downriver movements and coincidentally move through the shoals into deeper (>6 m) water (TI, 1981).

4.2.5 Yearling and Older Fish

Distribution of yearling and older white perch during the August through October Fall Shoals and Beach Seine surveys was very similar to the distribution of young-of-the-year (Figures 4.2-9 and 4.2-10). Yearling and older fish were concentrated in the shoal and bottom strata of the upper estuary and in the shore zone of the lower estuary. This distribution is characteristic of white perch in the Hudson River during late summer and fall (TI, 1981; Battelle, 1983). Yearlings comprised about half of the standing crop of yearling and older white perch in the shore zone while approximately 75% of the fish

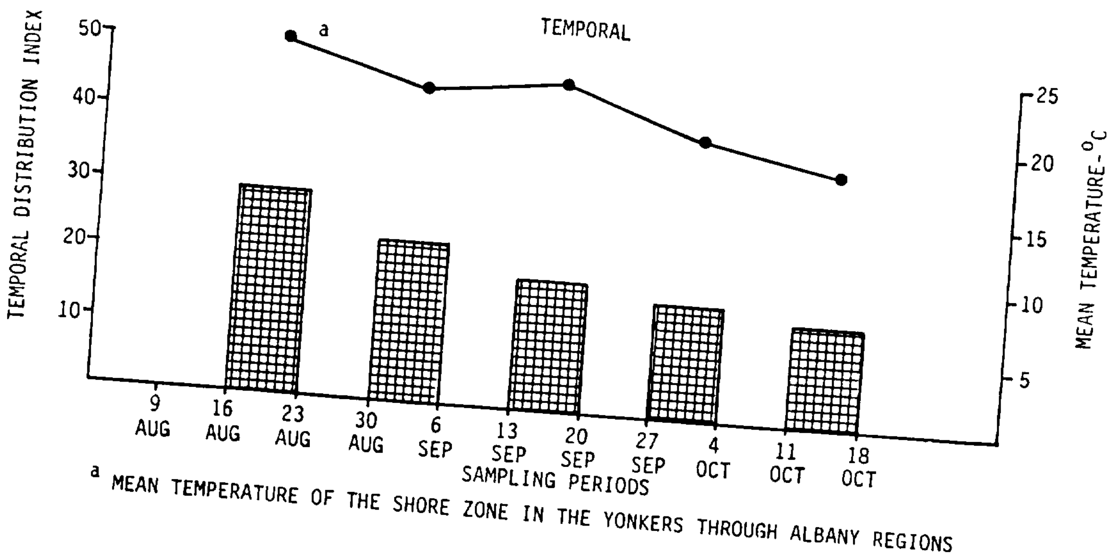


[a] MEAN TEMPERATURE OF THE OFFSHORE STRATA IN THE INDIAN POINT THROUGH ALBANY REGIONS



[b] MEAN CONDUCTIVITY OF THE OFFSHORE STRATA BY REGION FROM 9 AUGUST THROUGH 18 OCTOBER

Figure 4.2-7. Patterns in distribution of white perch young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals survey).



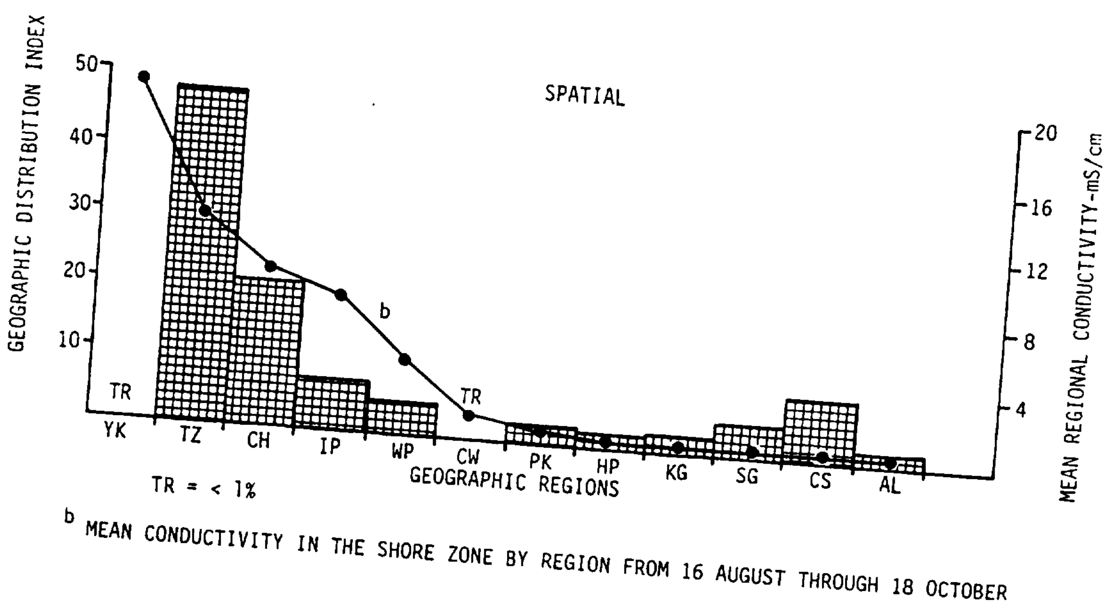


Figure 4.2-8. Patterns in distribution of white perch young-of-the year, Hudson River estuary, 1982 (based on Beach Seine survey).

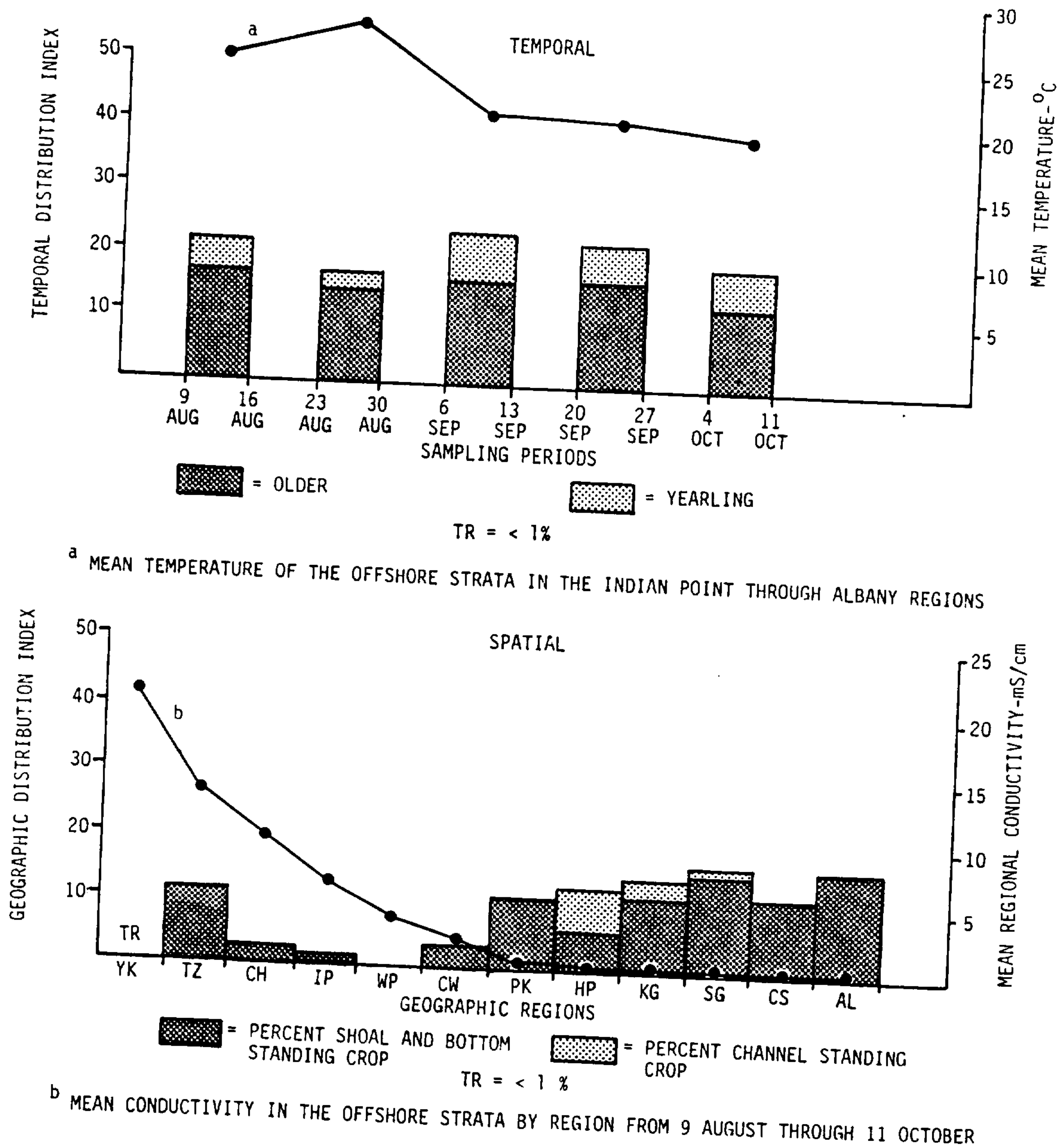


Figure 4.2-9. Patterns in distribution of white perch yearling and older, Hudson River estuary, 1982 (based on Fall Shoals survey).

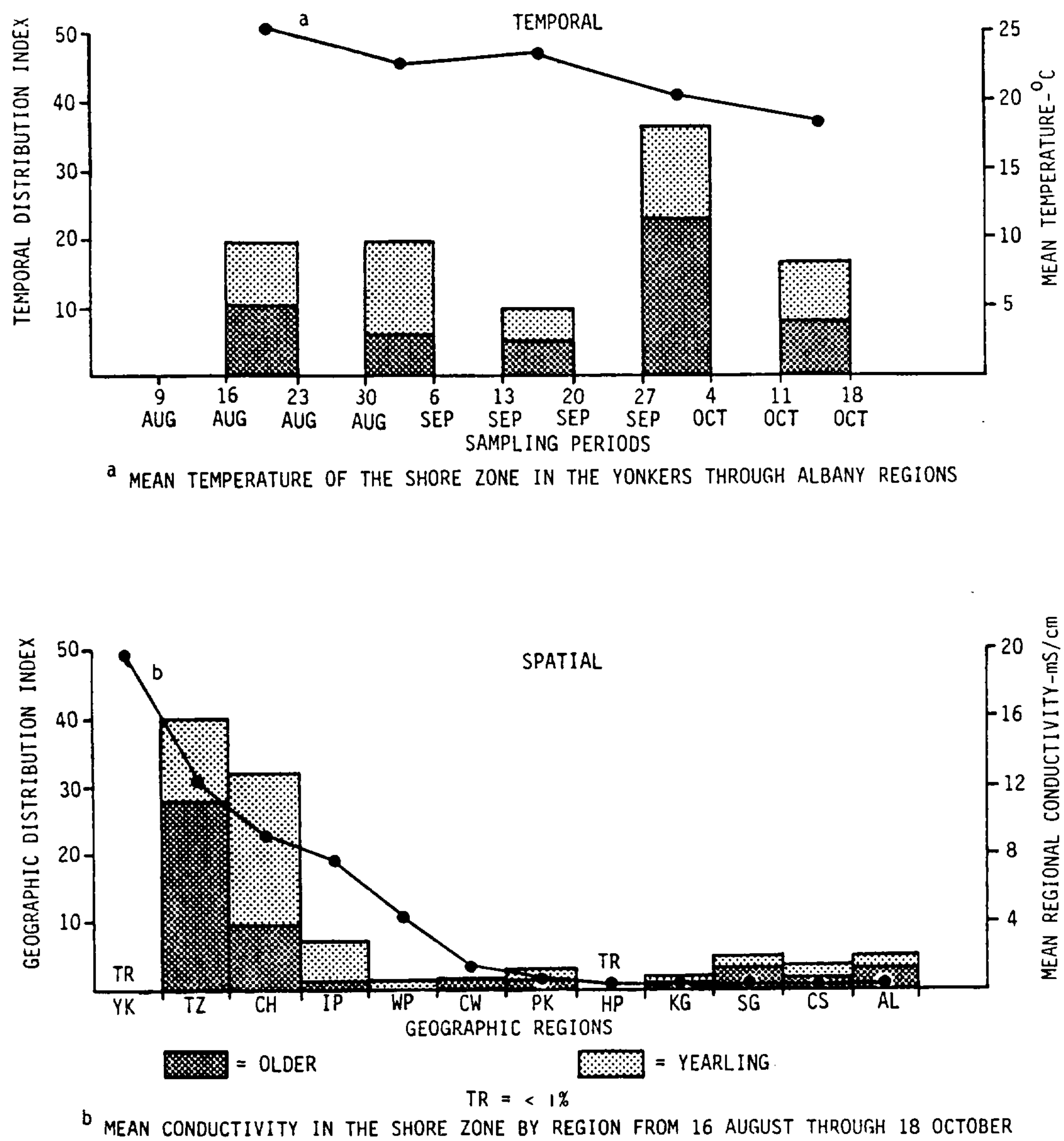


Figure 4.2-10. Patterns in distribution of white perch yearling and older, Hudson River estuary, 1982 (based on Beach Seine sampling).

in the offshore strata were older than yearling. This may reflect a preference by the older fish for deeper offshore waters.

Standing crop in the offshore strata was reasonably consistent during the course of the Fall Shoals survey, while in the shore zone, there was evidence of a temporary movement into the shore zone during late September and early October. This may reflect a movement of adults from the tributaries as temperatures decline. An offshore and downriver movement of white perch adults during fall and early winter has been described in past reports (TI, 1981).

4.3 AMERICAN SHAD

The American shad, *Alosa sapidissima* (Wilson), is one of the representatives of the family Clupeidae found in the Hudson River estuary. American shad are anadromous and range from Newfoundland to Florida. Adult shad may be found throughout the Hudson River estuary during the spawning season.

American shad spend the majority of their lives in the waters of the continental shelf (Bigelow and Schroeder, 1953); they are rarely found in freshwater outside of the spawning season (Mansueti and Hardy, 1967). Spawning usually occurs in tidal freshwater over areas with extensive flats. Spawning in the Hudson River occurs primarily in the Hyde Park to Catskill regions (RM 77-124) during early spring when water temperatures range from 7 to about 14°C (Talbot, 1954; TI, 1981).

Although American shad may spawn many times during their lifetime, there is a high mortality rate associated with spent American shad in the Hudson River. This phenomenon is due to the heavy energetic demands of the spawning migration and the limited availability of suitably sized food particles in fresh water which lead to weight loss (Leggett, 1972). Those shad that survive leave the estuary and return to sea, migrating northward to the Gulf of Maine (Scott and Crossman, 1973).

Shad eggs are demersal and non-adhesive; incubation time ranges from 2 days at 27°C to 17 days at 12°C (Mansueti and Hardy, 1967). The yolk-sac larvae are 6-10 mm in length upon hatching and absorb their yolk sac within 5 days at 17°C, at which time they measure 9-12 mm in length (Mansueti and Hardy, 1967). They spend their first summer within the estuary, feeding on copepods, ostracods and amphipods. During fall, juvenile shad (approximately 90 mm TL) begin to migrate out of the estuary.

4.3.1 Eggs

American shad eggs were most abundant in the Hudson River estuary during the first week of sampling (10-17 May); mean densities greater than 1000/1000 m^3 occurred in both the Saugerties and Albany regions. Most shad eggs were concentrated in the bottom stratum in the upper estuary; none were collected downriver of the Poughkeepsie region (Figure 4.3-1). This geographic distribution was generally similar to that reported from 1979 through 1981 (TI, 1981, Battelle, 1983). However, in 1982, most of the standing crop occurred in the Saugerties region, whereas from 1979 through 1981 the Albany region had the highest standing crop (TI, 1981; Battelle, 1983). From 1976 through 1978 a bimodal temporal distribution was observed with maximum standing crop in the Catskill region (TI, 1981).

Temperatures in the Saugerties to Albany regions during the second week of May averaged 13.0°C (Table 4.3-1), somewhat lower than the optimum for survival and development of shad eggs (16°C; Marcy, 1972). Mean temperatures during maximum egg abundance approached or exceeded 16°C during only two of seven years since 1976 (Table 4.3-1). Thus it appears that American shad spawning in the Hudson River estuary frequently occurs earlier than the period of optimum environmental temperature. Spawning of shad during suboptimal conditions has been noted in the Connecticut River and was associated with a weakened year class (Marcy, 1976a).

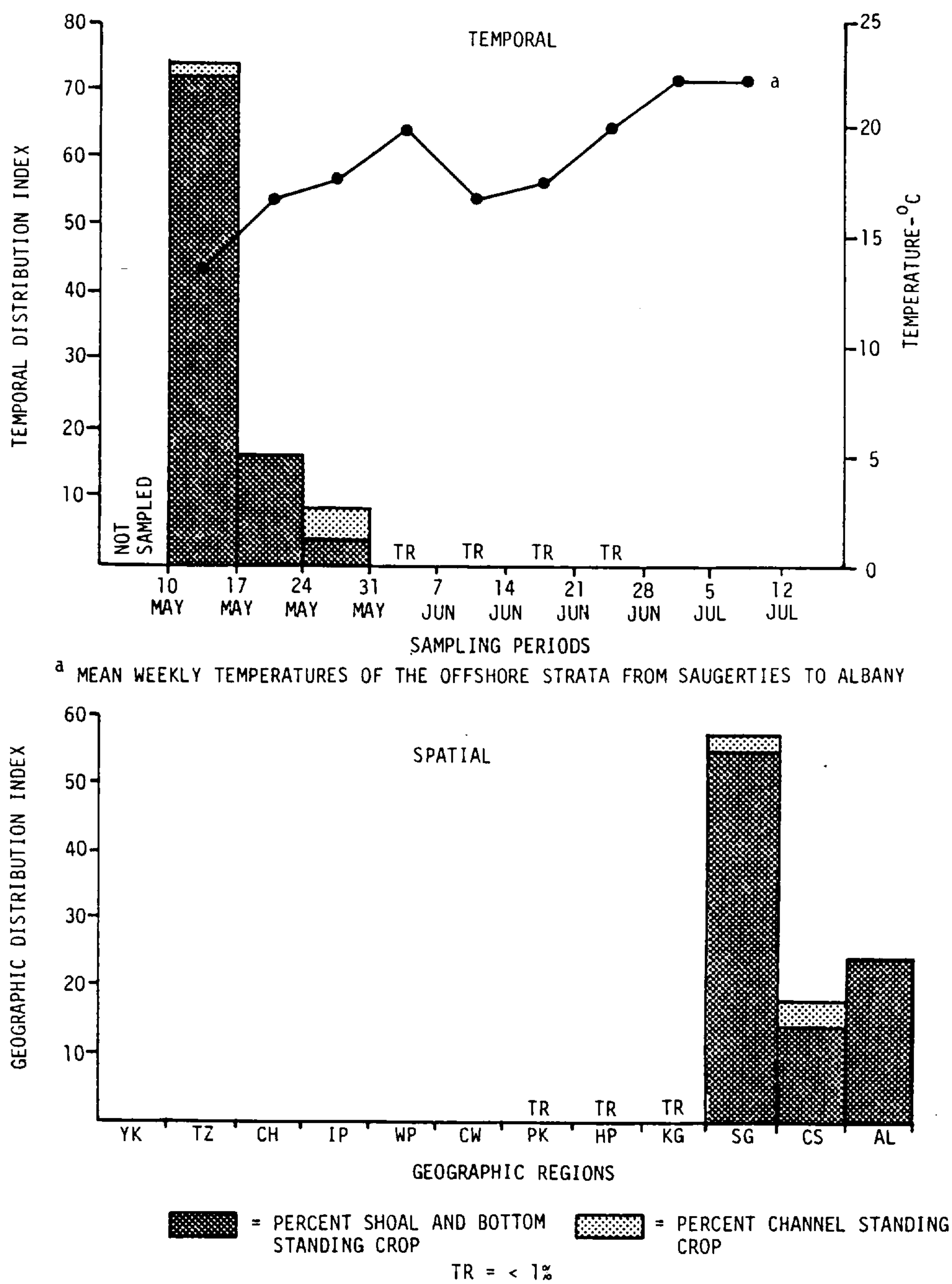


Figure 4.3-1. Patterns in distribution of American shad eggs, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

TABLE 4.3-1. MEAN AND RANGE OF WATER TEMPERATURES (^{o}C) IN REGIONS AND PERIODS OF PEAK ABUNDANCE OF AMERICAN SHAD EGGS AND LARVAE, HUDSON RIVER ESTUARY, 1976 THROUGH 1982.

	EGGS			YOLK-SAC LARVAE			POST YOLK-SAC LARVAE		
YEAR	WEEK(S)	MEAN	RANGE	WEEK(S)	MEAN	RANGE	WEEK(S)	MEAN	RANGE
1976	02 May - 22 May	13.3	11.2-15.0	09 May- 12 Jun	15.6	12.3-20.1	13 Jun - 26 Jun	22.9	21.7-23.8
1977	01 May - 21 May	13.5	12.0-16.4	08 May - 28 May	16.6	12.6-20.4	22 May - 04 Jun	20.5	20.4-20.6
1978	30 Apr - 27 May	13.1	8.5-17.1	21 May - 03 Jun	14.8	12.9-17.1	28 May - 03 Jun	21.4	21.1-21.6
1979	13 May - 19 May	17.3	17.0-17.7	13 May - 26 May	18.0	17.1-18.9	10 Jun - 16 Jun	19.4	19.4-19.4
1980	05 May - 08 May	15.5	*	12 May - 15 May	15.5	*	02 Jun - 13 Jun	20.0	*
1981	04 May - 09 May	10.0	*	18 May - 21 May	15.8	*	18 May - 21 May and	15.8	*
							08 Jun - 13 Jun	21.0	*
1982	10 May - 14 May	13.0	13.0-13.2	17 May - 20 May	16.6	16.5-16.7	24 May - 03 Jun	18.5	17.2-20.1

* individual values not reported

1976-1979 data from TI, 1981
1980-1981 data from Battelle, 1983

4.3.2 Yolk-Sac Larvae

American shad yolk-sac larvae peaked during the third week of May, one week after the egg abundance peak. The highest standing crop occurred in the Albany region, with very few yolk-sac larvae found downriver from Kingston (Figure 4.3-2). Temperature at this time had risen to 16.6^{o}C in the upper estuary (Table 4.3-1). Distribution of shad yolk-sac larvae in 1982 was consistent with that reported from 1979 through 1981 (TI, 1981; Battelle, 1983); however, this developmental stage was distributed further downstream from 1976 through 1978 (TI, 1981).

4.3.3 Post Yolk-Sac Larvae

Shad post yolk-sac larvae were most abundant in late May-early June, one to two weeks after the yolk-sac larva peak (Figure 4.3-3). Downstream movement was clearly evident; larval distribution had shifted from the bottom to the channel stratum and, while still concentrated in the upper estuary, larvae were collected at all downriver locations except for Yonkers (Figure 4.3-3). Weekly distributions from 17 May through 14 June illustrate that maximum standing crop alternated among the Kingston, Saugerties and Catskill regions (Figure 4.3-4), and that downstream movement became most obvious between the late May and early June samplings.

The spatial distribution of post yolk-sac larvae in 1982 was very similar to that reported from 1976 through 1981 (TI, 1981; Battelle, 1983). Maximum abundance generally occurred in the last week of May and the first week in June, except in 1976 and 1979, when the peak occurred in mid to late June (Table 4.3-1).

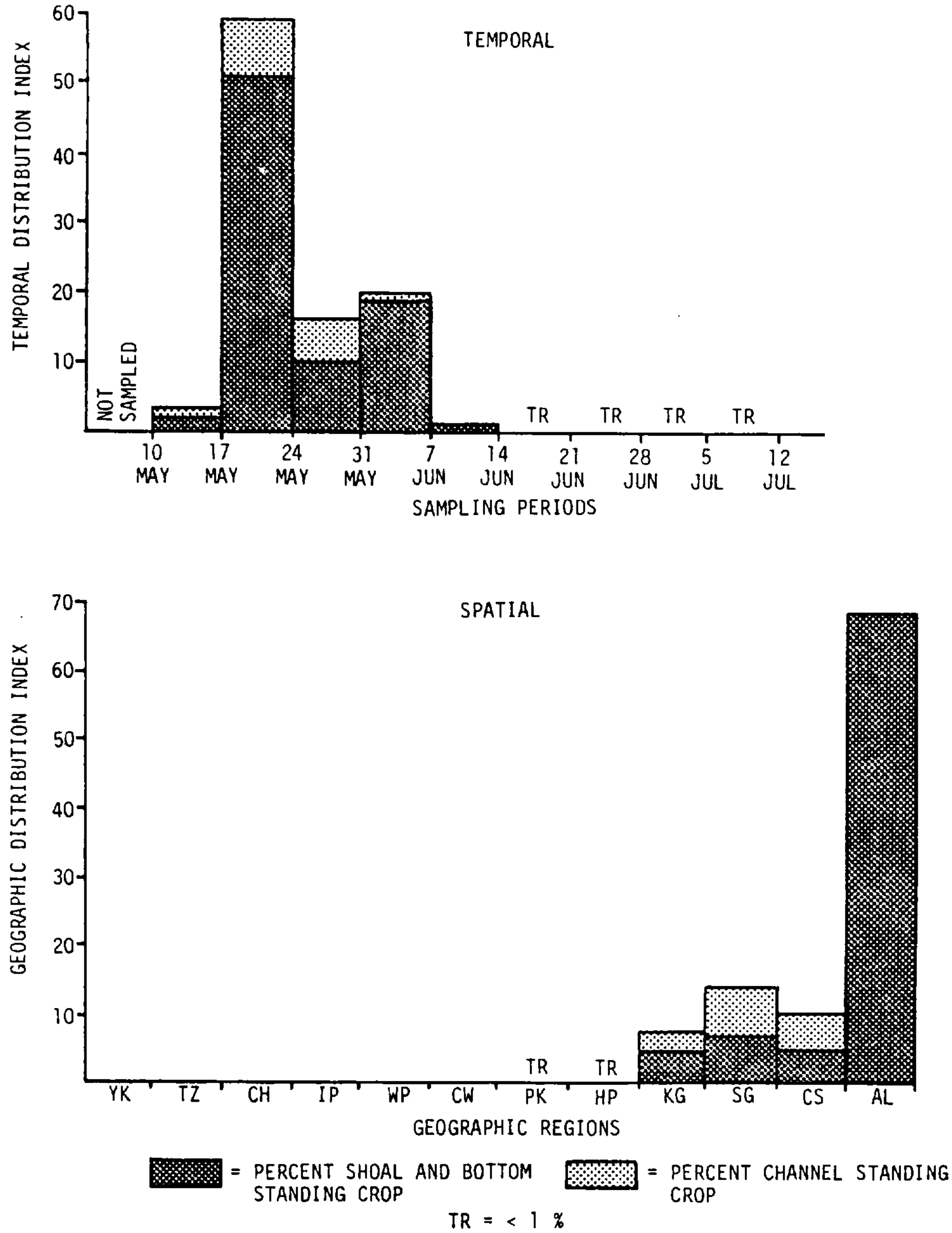


Figure 4.3-2. Patterns in distribution of American shad yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

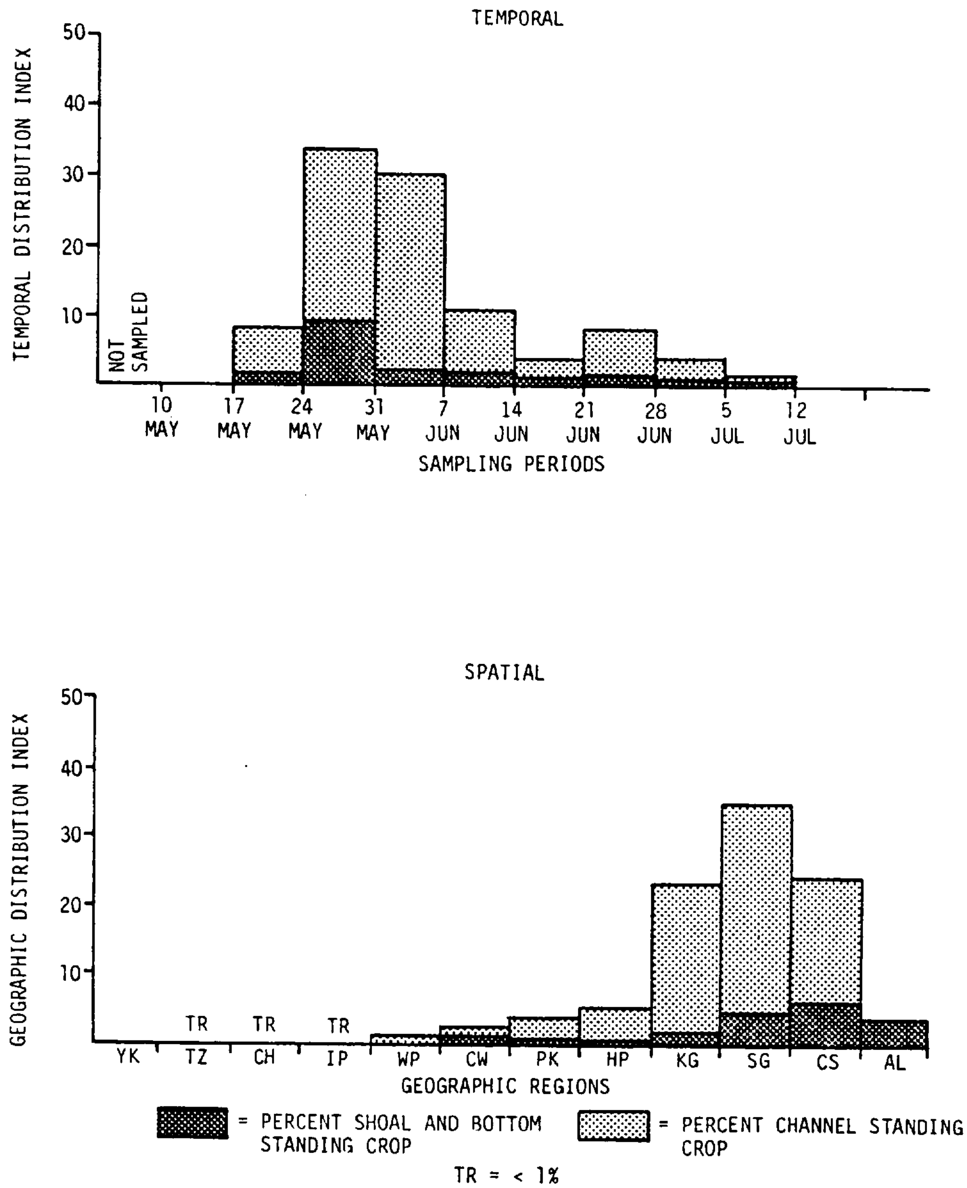


Figure 4.3-3. Patterns in distribution of American shad post yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

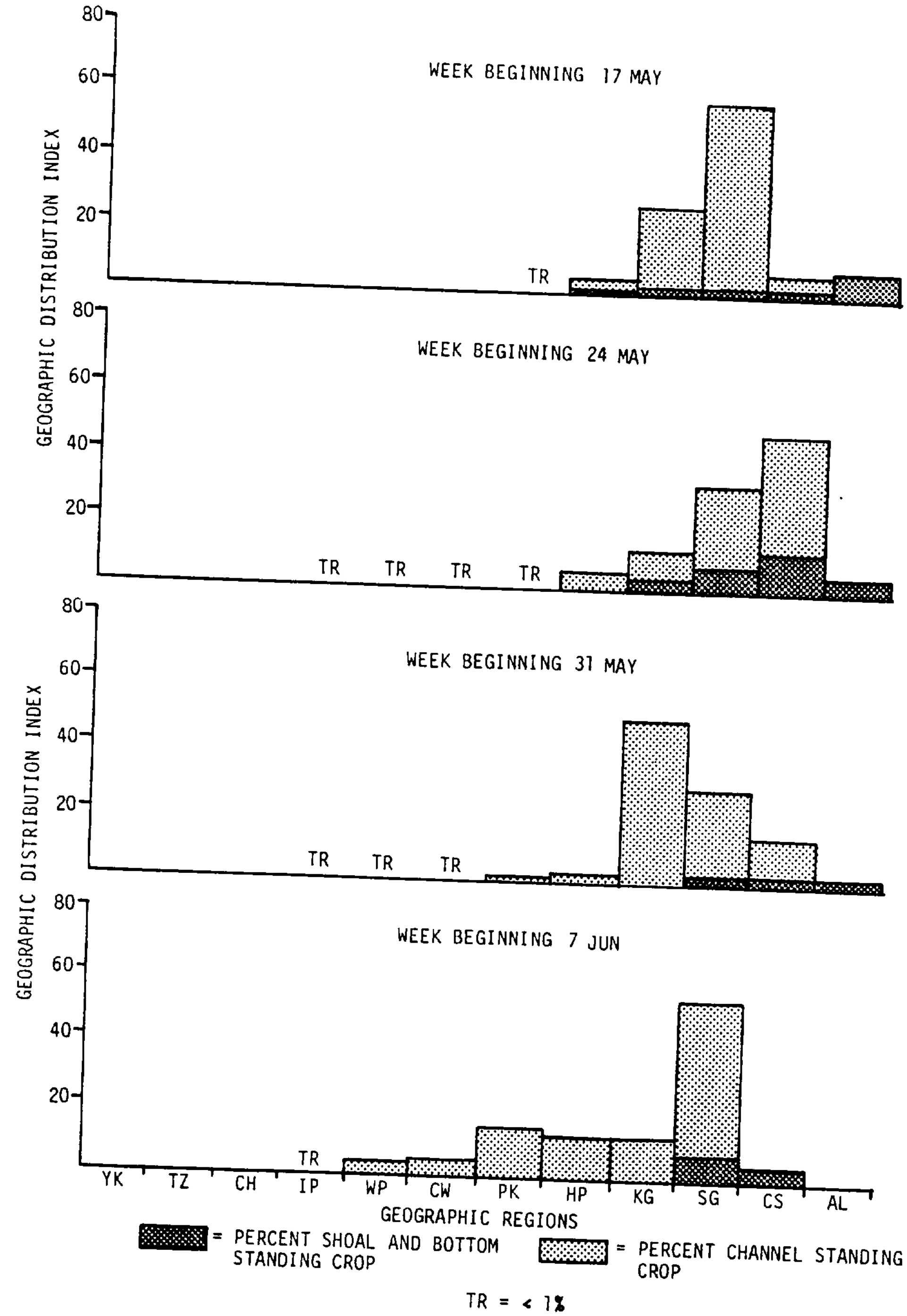


Figure 4.3-4. Weekly geographic distribution of American shad post yolk-sac larvae during the period of peak abundance, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

4.3.4 Young-of-the-Year

Transformation of American shad from the post yolk-sac to the juvenile stage began by mid to late June during the ichthyoplankton sampling (Figure 4.3-5). Water temperatures during this period averaged between 18° and 21°C throughout the estuary. Unlike earlier developmental stages, which were concentrated in the upper estuary, juvenile shad were dispersed throughout most of the estuary (Figures 4.3-5, 4.3-6 and 4.3-7). Highest abundances throughout the August to October sampling program, however, occurred in the middle to upper estuary.

Downstream movements of juvenile shad were not clearly detected in 1982. Dispersion downstream apparently occurs primarily during July while water temperatures are rising (TI, 1981) as the population matures from the larval to the juvenile stage. In the Connecticut River, however, juveniles disperse seaward in August when water temperatures begin to decline (Marcy, 1976a). Emigration from the Hudson River estuary is virtually complete by late October (TI, 1981). According to Leggett and Whitney (1972), juvenile shad emigrate from rivers along the Atlantic coast following a drop in water temperature below 15.5°C for several days. In 1982, Hudson River temperatures were above 18°C in early October when the sampling program ended; no clear evidence of emigration from the estuary was observed.

4.3.5 Yearling and Older Fish

Yearling and older shad were collected in extremely low numbers on only six occasions during the 1982 sampling program (Appendix B; Tables B-30, B-31 and B-32). Occurrences were sporadic and no conclusions could be drawn regarding distribution.

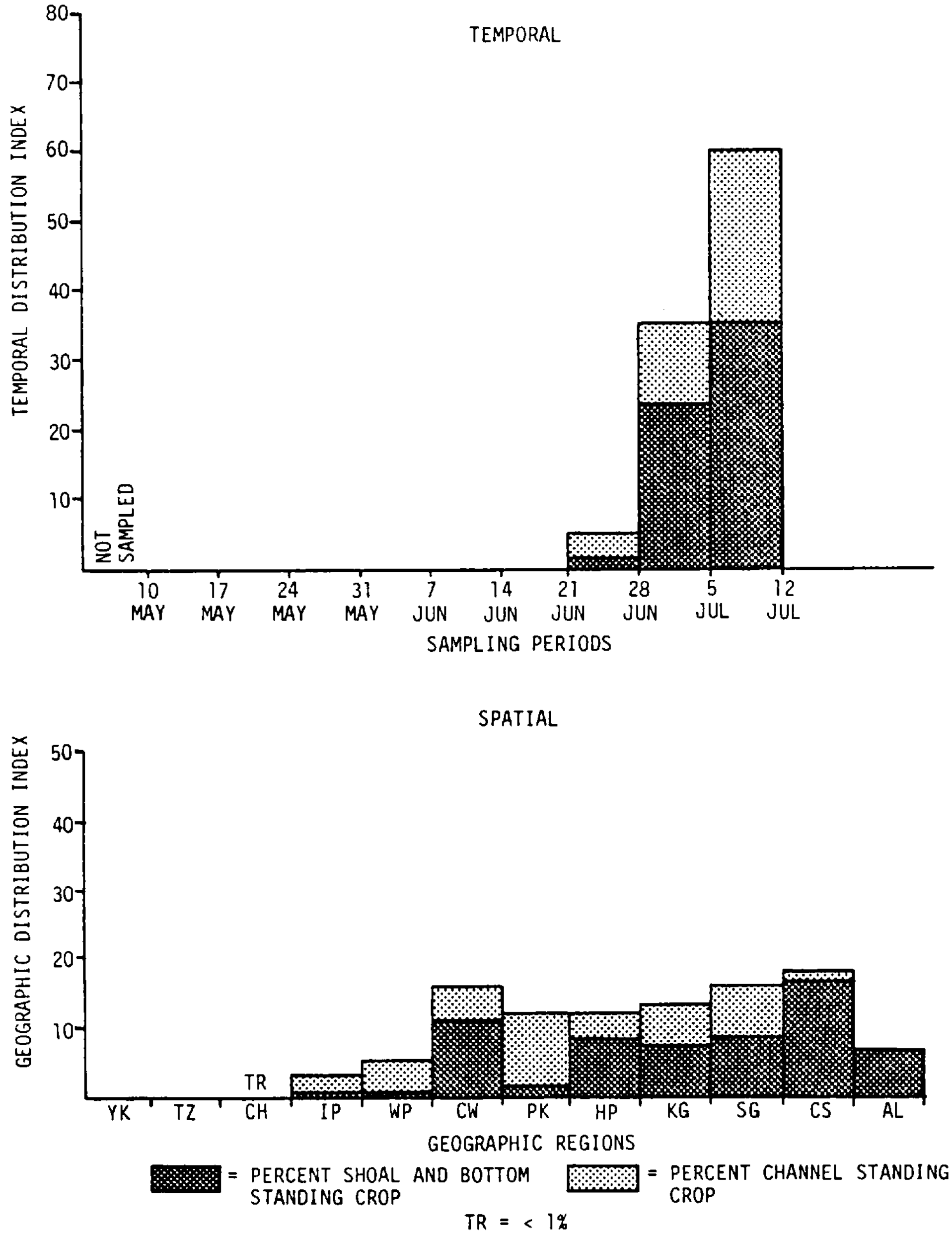


Figure 4.3-5. Patterns in distribution of American shad young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

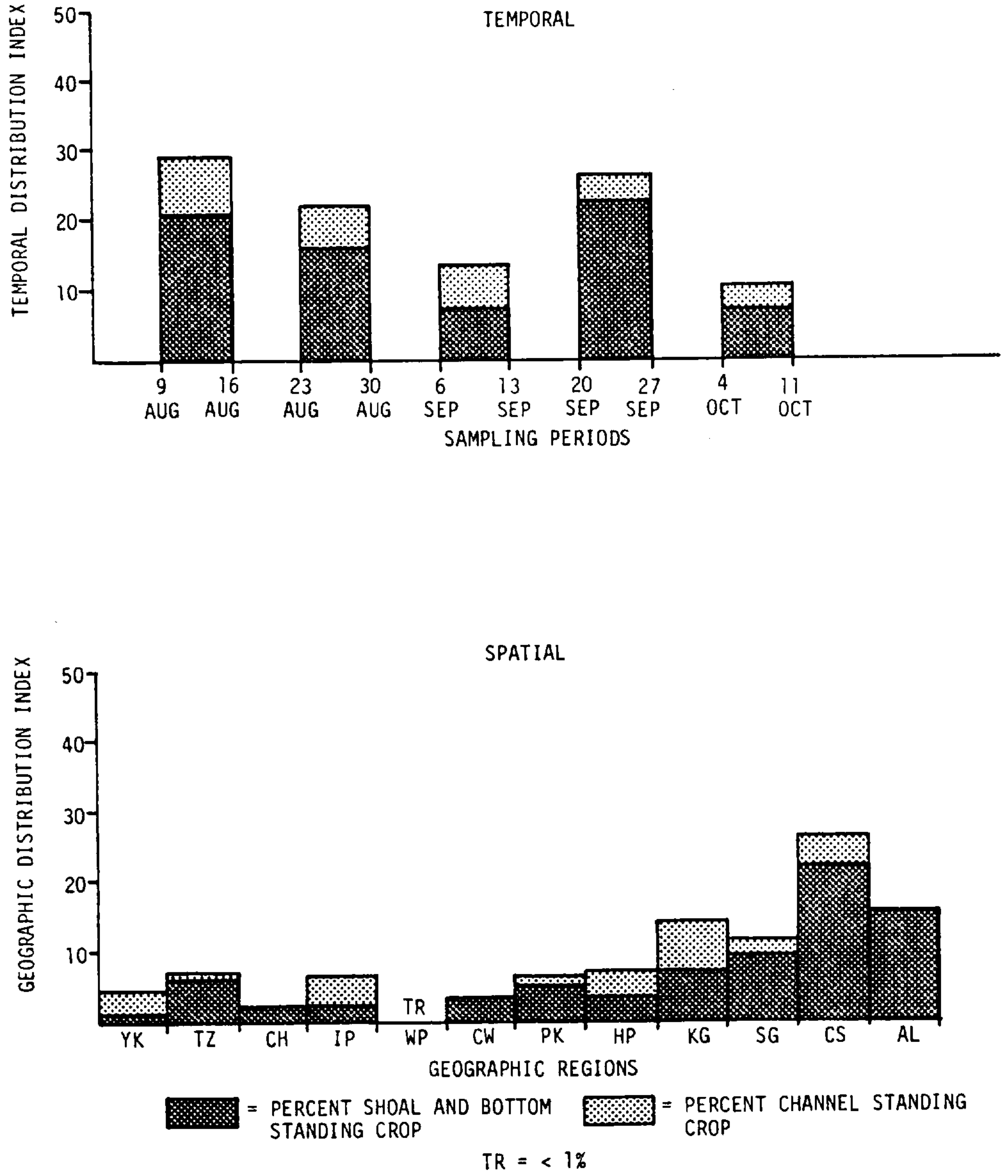


Figure 4.3-6. Patterns in distribution of American shad young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals sampling).

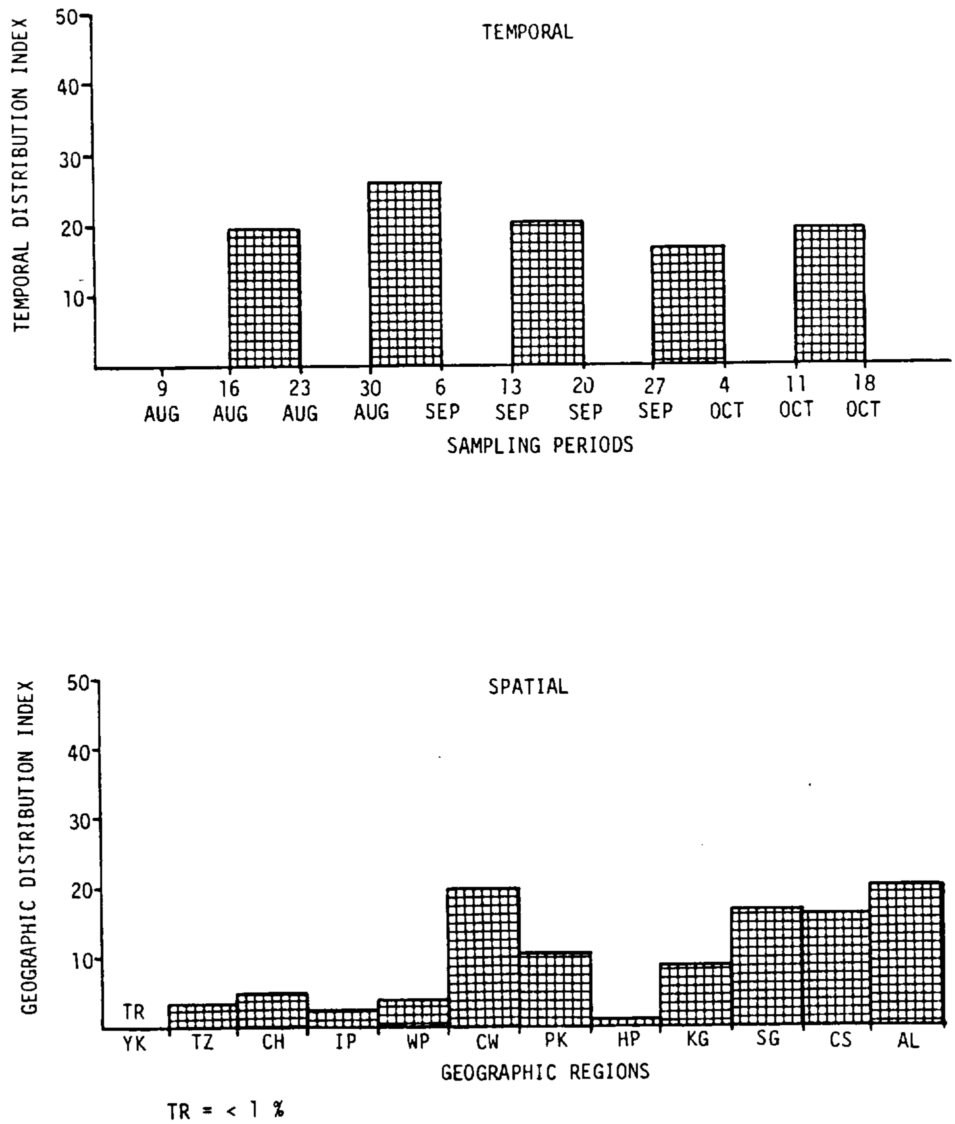


Figure 4.3-7. Patterns in distribution of American shad young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine sampling).

4.4 ATLANTIC TOMCOD

The Atlantic tomcod, *Microgadus tomcod* (Walbaum), is a euryhaline species of the family Gadidae closely resembling its marine relative the Atlantic cod. The Atlantic tomcod can be found along the Atlantic coast from the maritime provinces of Canada south to Virginia. Tomcod frequently occur in estuaries and their tributaries but also may be found in coastal waters, as much as 1.6 kilometers offshore (Bigelow and Schroeder, 1953). Within the Hudson River they usually are found below Kingston (RM 86) but occasionally occur as far north as Saugerties (RM 106).

The tomcod spawn from November through February over sand or gravel bottoms in brackish and occasionally freshwater shoal areas (Scott and Crossman, 1973). In the Hudson River estuary adults usually reach sexual maturity by Age I. The number of eggs produced is dependent upon the size of the female, and ranges from 1600 to 86,000 eggs with an average of 20,000 eggs. The eggs are about 1 mm in diameter, demersal and adhesive. Since the Atlantic tomcod is a winter spawner, incubation time is about 24 days at 6°C. The newly-hatched larvae are approximately 5 mm in length and absorb the yolk sac within 4-5 days.

During the summer, tomcod juveniles of the Hudson River population occur not only in the middle estuary where they were spawned, but in the lower estuary, in adjacent coastal waters below the sampling area, and also in areas upriver of the spawning area (TI, 1981). The dispersion upriver is associated with brackish water extending farther upriver during that season. By the time the winter spawning season arrives, the tomcod are mature and are concentrated in coastal areas and the lower estuary prior to their spawning migration (TI, 1981). This distribution implies that the juveniles which occurred upriver in the summer have moved downriver during the fall, which is a period when salinities in the middle estuary are generally decreasing.

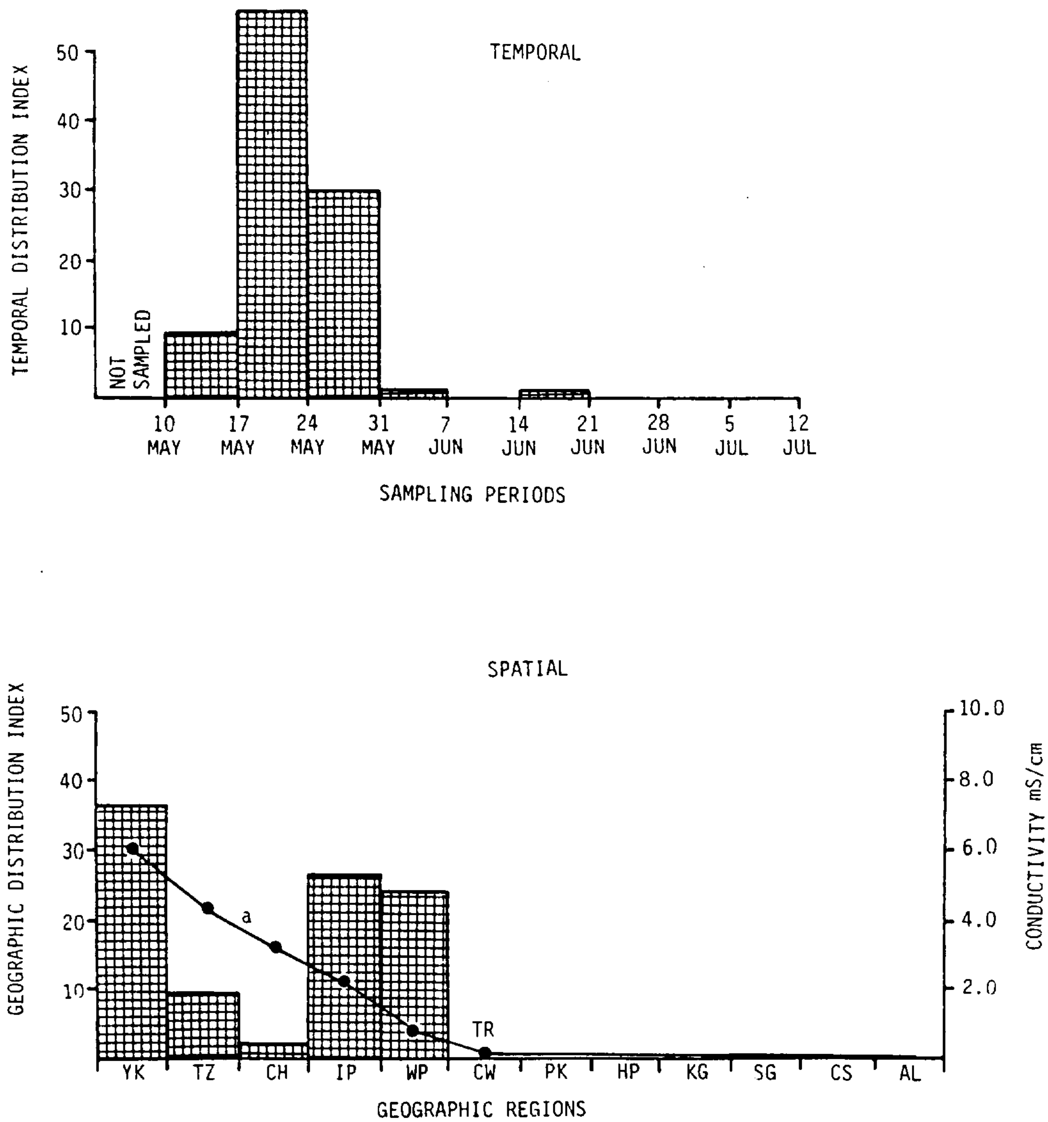
The tomcod is one of the smallest species of the Gadidae, obtaining a total length of 130-150 mm after one year and reaching a maximum length of 350 mm and a weight of 450 grams. Size notwithstanding, tomcod feed heavily on small crustaceans such as shrimp and amphipods.

4.4.1 Post Yolk-Sac Larvae

Since the Atlantic tomcod is a midwinter spawner, no eggs or yolk-sac larvae were collected. Post yolk-sac larvae were present but only in trace abundances, and probably had past their peak when sampling began in May. Regional densities of post yolk-sac larvae during ichthyoplankton sampling were always below 10/1000 m^3, and in most cases densities were less than 1/1000 m^3. In all previous years (1974-1981), post yolk-sac larvae reached peak abundance during April when water temperatures were between 6^{O}-$12^{O}C$ and declined to trace levels in May and June (TI, 1981). Thus, post yolk-sac larvae collected in May and June during the current sampling period constitute only a small portion of their total occurrence during the 1982 season. As in past years, post yolk-sac larvae were collected as far north as Cornwall (RM 56-61), but were more abundant downriver in the Yonkers, Indian Point, and West Point regions (Figure 4.4-1).

4.4.2 Young-of-the-Year

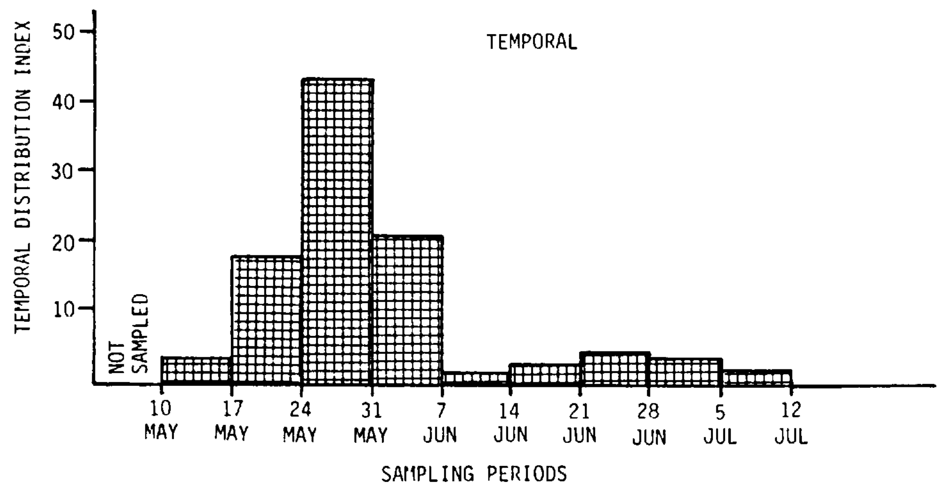
Juvenile Atlantic tomcod were collected when sampling began the week of 10 May and reached maximum abundance during late May and early June (Figure 4.4-2). This period is the same as was observed in 1979 but approximately one month later than observed in 1974-1978 and 1981 (TI. 1981; Battelle, 1983). As described in the 1979 Year Class Report a large portion of the post yolk-sac population was probably distributed downriver of the study area, and juveniles were very likely distributed in a similar manner. Therefore, the delayed appearance of juvenile Atlantic tomcod may be associated with the period of movement



[a] MEAN REGIONAL CONDUCTIVITY DURING THE PERIOD OF PEAK OCCURRENCE 10 MAY - 7 JUN.

TR = < 1%

Figure 4.4-1. Patterns in distribution of Atlantic tomcod post yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).



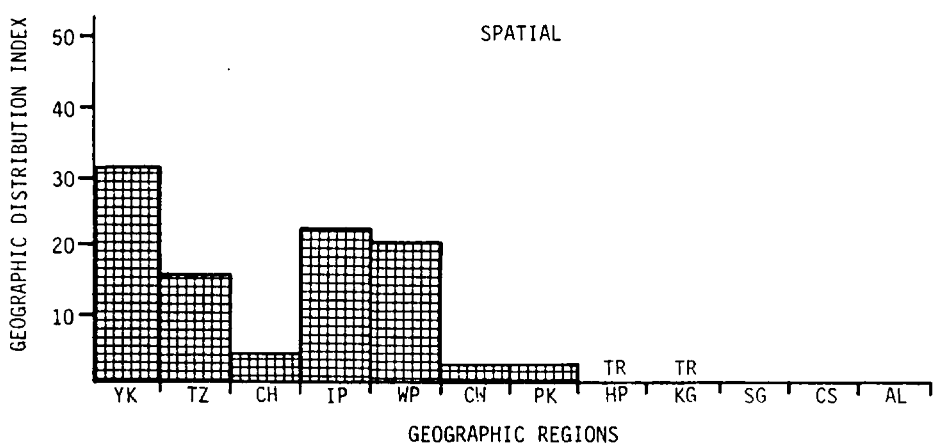


Figure 4.4-2. Patterns in distribution of Atlantic tomcod young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

upstream into the study area. This movement can be observed in Figure 4.4-3, where during each week up to the time of peak abundance, increasing densities were taken in the Yonkers region.

Juvenile standing crop began to decrease by the beginning of June, largely due to emigration and gear avoidance (TI, 1981). The spatial distribution of these early juveniles was the same as previous years, except for the additional peak in the Indian Point and West Point regions. This could be due to the large portion of post yolk-sac larvae that were also in this region.

The offshore distributional pattern of juveniles from August through October (Figure 4.4-4) was similar to the patterns observed for all previous years except 1979 and 1980 (TI, 1981; Battelle, 1983). Peak abundance of juveniles in the offshore strata occurred in early August; most juveniles were located in the middle estuary. Conductivity during this period averaged 2.3 mS/cm (Figure 3.3-1), with the salt front located approximately in the Poughkeepsie region.

The spatial distribution of juveniles was the same as previous years, except for 1976 and 1979 when the peaks occurred downriver in the Tappan Zee and Yonkers region (TI, 1981). These annual differences in distribution were related to lower conductivities in the middle estuary during 1976 and 1979 (TI, 1980a, 1981). Atlantic tomcod prefer brackish water and during times of relatively low conductivities may move farther downriver with the salt front.

Downstream movement of juveniles in the fall began about mid-September. At this time, densities of juveniles in the off-shore strata began to decline while numbers in the shore zone remained relatively constant (Figures 4.4-4 and 4.4-5). Most juveniles in the shore zone werecollected in the lower estuary, particularly in the Tappan Zee region.

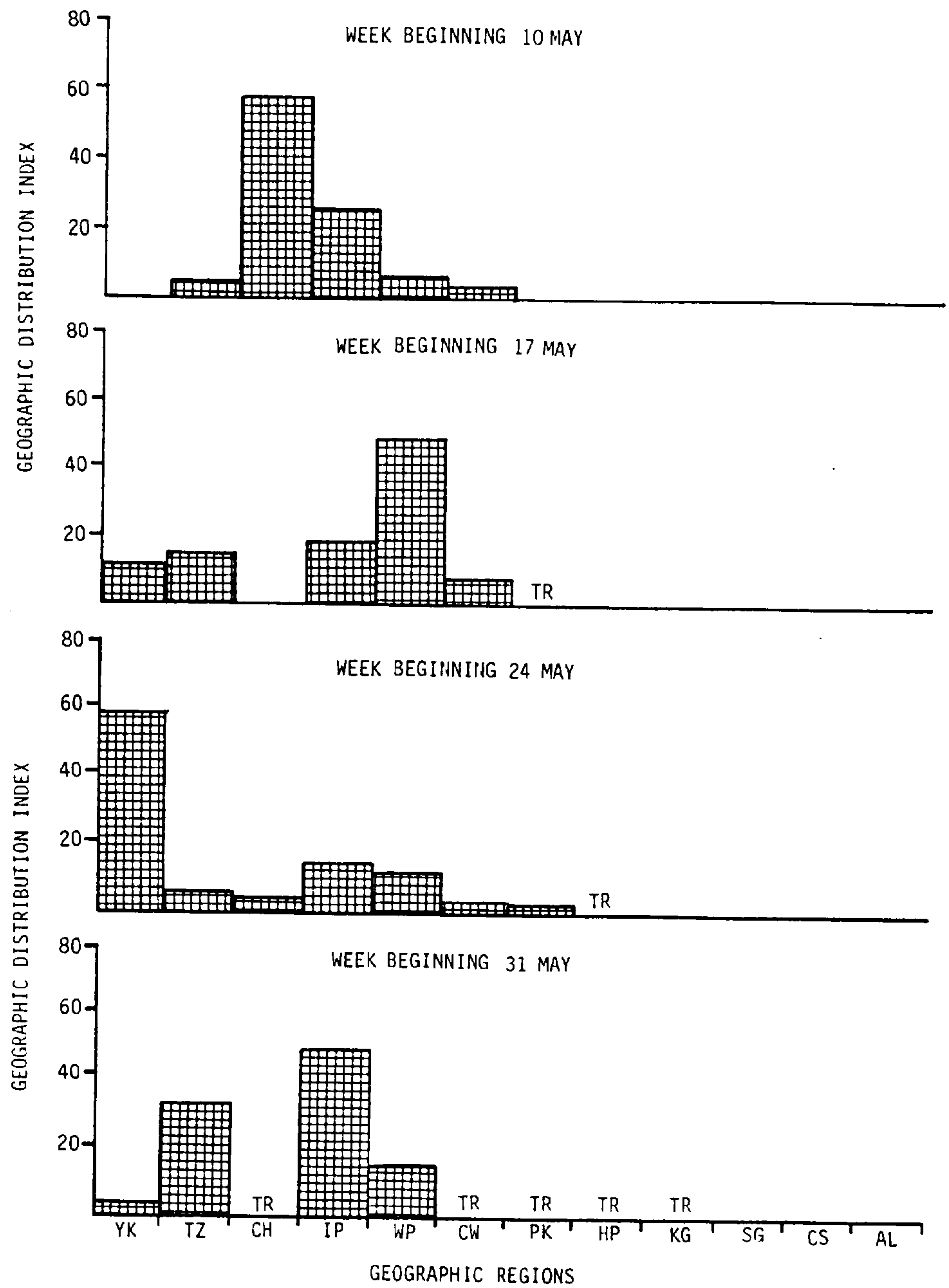
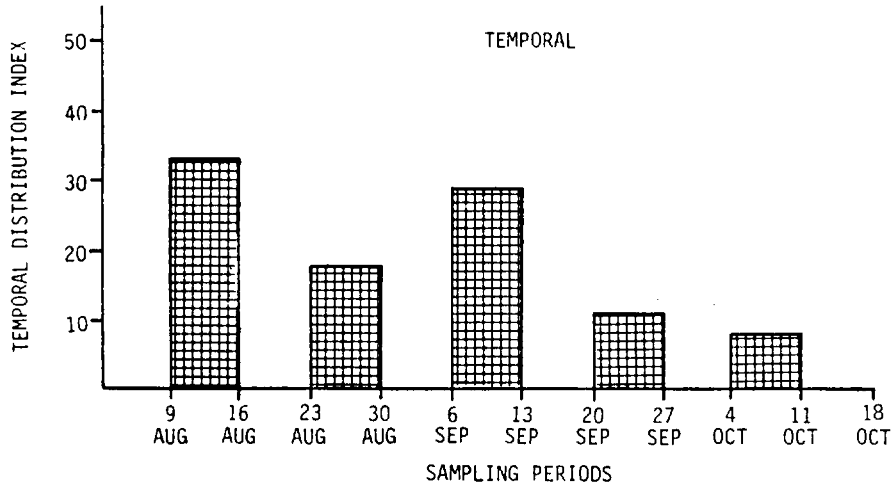


Figure 4.4-3. Weekly geographic distribution of Atlantic tomcod young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).



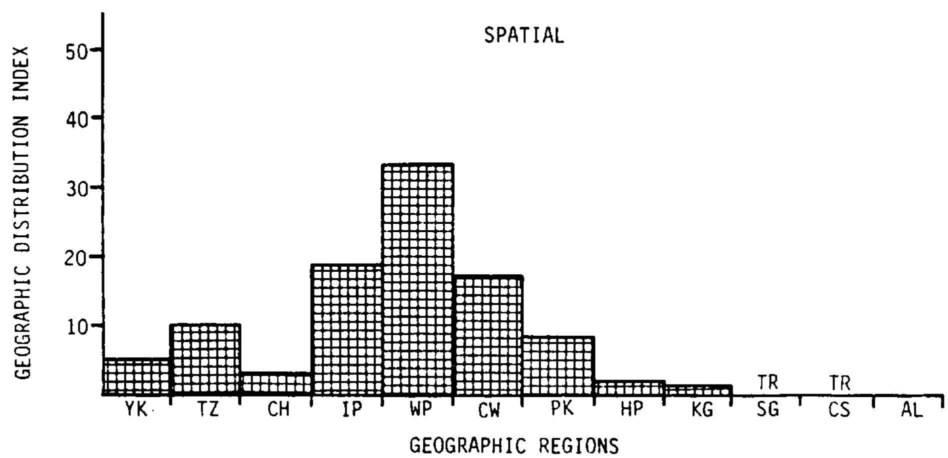


Figure 4.4-4. Patterns in distribution of Atlantic tomcod young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals sampling).

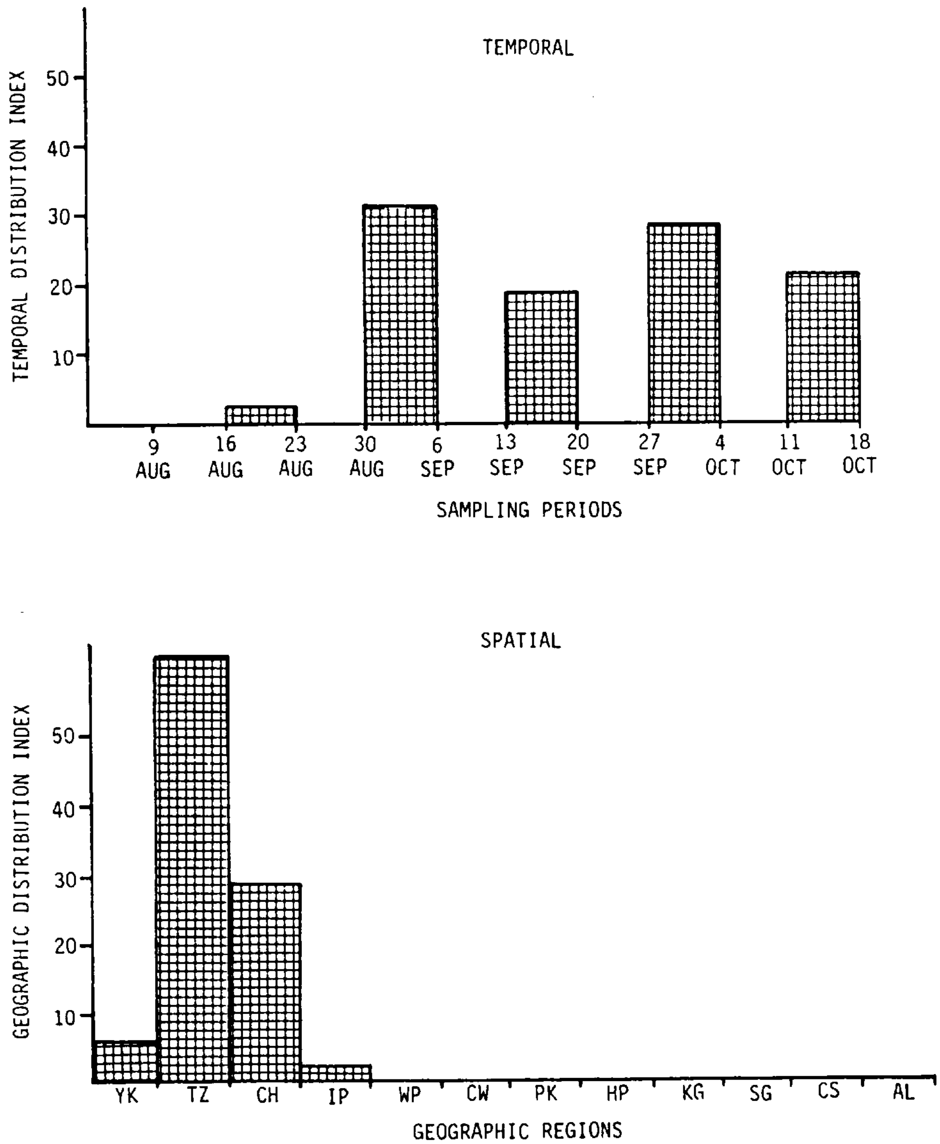


Figure 4.4-5. Patterns in distribution of Atlantic tomcod young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine sampling).

4.5 UNIDENTIFIED CLUPEIDS

This category comprises the early developmental stages of two anadromous clupeids, blueback herring and alewife, which are collectively referred to as river herring. Both of these species spawn in the spring. Blueback herring spawn somewhat later than alewives, although the blueback spawning migration may overlap the end of the alewife spawning period. These species are difficult to distinguish until the metamorphosed juveniles reach a total length of 35 to 40 mm (TI, 1981). In the following section, the distribution of river herring eggs, yolk-sac larvae, post yolk-sac larvae and young juveniles will be presented and discussed.

4.5.1 Eggs

Maximum standing crop of river herring eggs occurred at the start of the sampling program during the second week in May (Figure 4.5-1). Eggs were concentrated in the Saugerties and Catskill regions. Water temperatures in the upper estuary during this period averaged 13.0°C.

Temporal distribution of river herring eggs in the upper estuary varied with geographic region (Figure 4.5-2). A unimodal peak in standing crop occurred in the Saugerties and Catskill regions in the second or third week of May, whereas a bimodal (third week of May and second week of June) peak was evident in the Albany region. This bimodal distribution may represent either sequential spawning by alewives and blueback herring or a second spawning by alewives. In 1979, TI (1981) reported two peaks of river herring eggs, with the second peak coinciding with peak catches of adult blueback herring. However, since alewives may spawn twice in the Albany area (LMS, 1975, cited in TI, 1981), the second peak in 1979 may have included alewives as well as blueback herring.

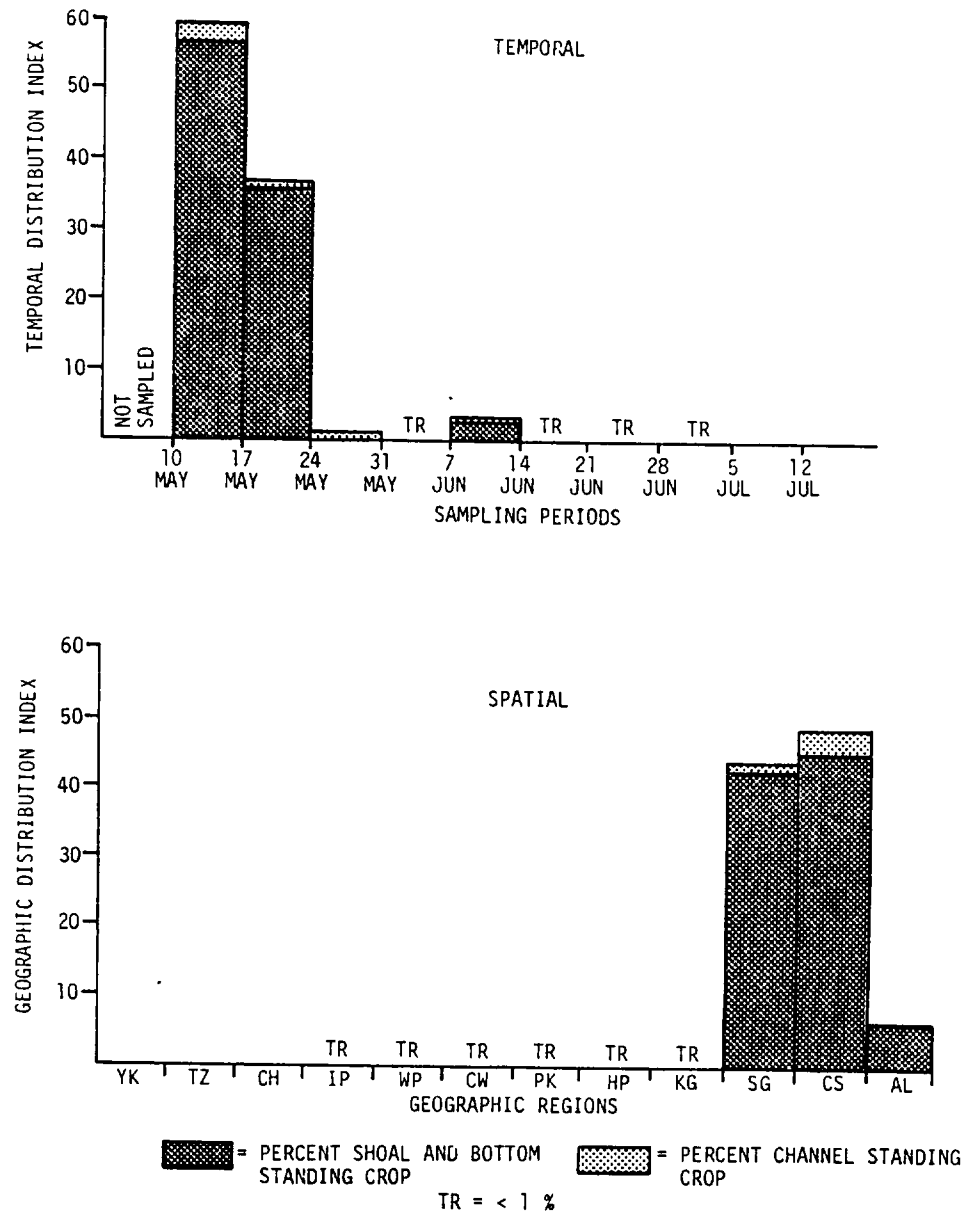


Figure 4.5-1. Patterns in distribution of unidentified clupeid eggs, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

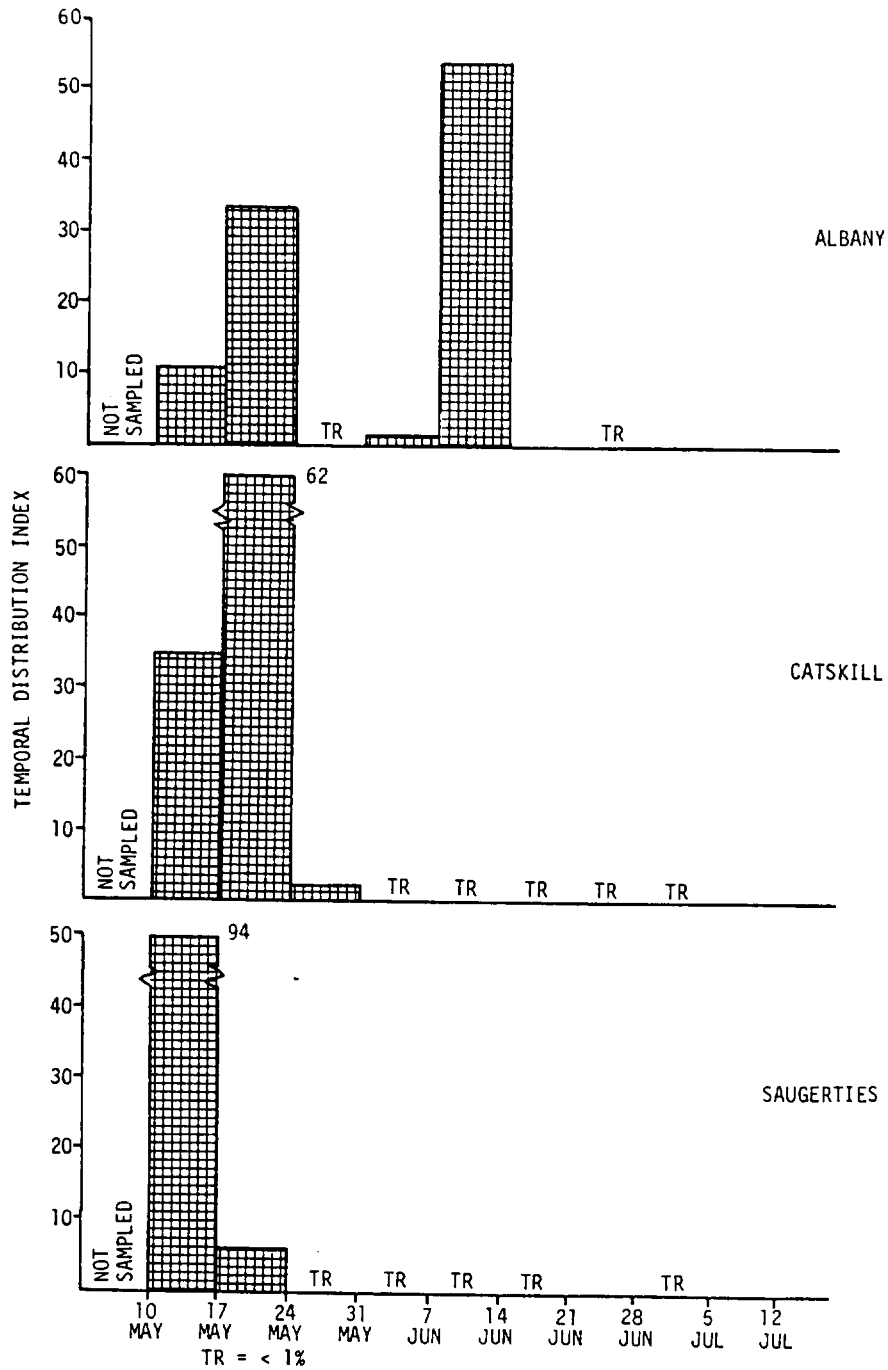


Figure 4.5-2. Temporal distribution of unidentified clupeid eggs in the regions of peak abundance, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

4.5.2 Yolk-Sac Larvae

Abundance of river herring yolk-sac larvae peaked during the third week in May, about one week after the egg abundance peak (Figure 4.5-3). Yolk-sac larvae were most abundant in the upper estuary, although they were slightly more dispersed downstream than were eggs. Whereas eggs were concentrated in the bottom strata, yolk-sac larvae were more evenly distributed vertically.

Regional differences in yolk-sac larvae abundance peaks were apparent (Figure 4.5-4). In the Catskill area, standing crop peaked during the second week in June whereas in the other upriver locations, the peak occurred three weeks earlier. The Catskill yolk-sac larvae peak coincided with the second Albany egg peak (Figure 4.5-2). Since incubation time for river herring eggs would be one week or less at temperatures recorded in the upper estuary during this period ($17^{o}C$), it is likely that these peaks represent the same spawning event.

4.5.3 Post Yolk-Sac Larvae

River herring post yolk-sac larvae were present during the second week in May and reached peak abundance during the last week in May and first week in June (Figure 4.5-5). Peak abundance had shifted slightly downriver to the Saugerties region. Most post yolk-sac larvae were found in the channel, continuing the trend of vertical dispersion observed for yolk-sac larvae. Temporal distribution among the regions from Catskill through Poughkeepsie was fairly constant (Figure 4.5-6). No bimodality was evident in temporal distribution as was observed with eggs and yolk-sac larvae.

4.5.4 Early Young-of-the-Year

River herring young-of-the-year first appeared in ichthyoplankton samples during the third week of June and were most abundant

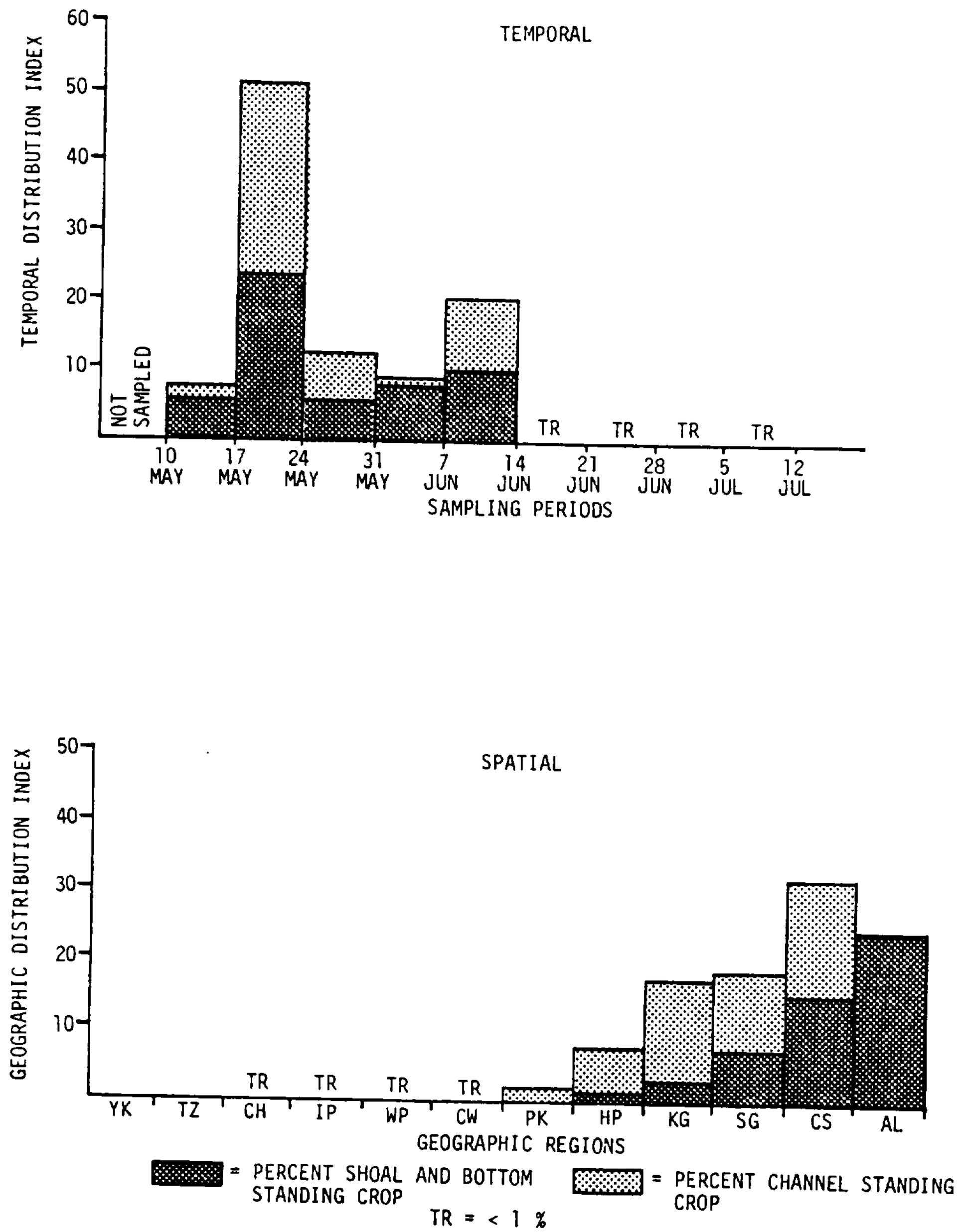


Figure 4.5-3. Patterns in distribution of unidentified clupeid yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

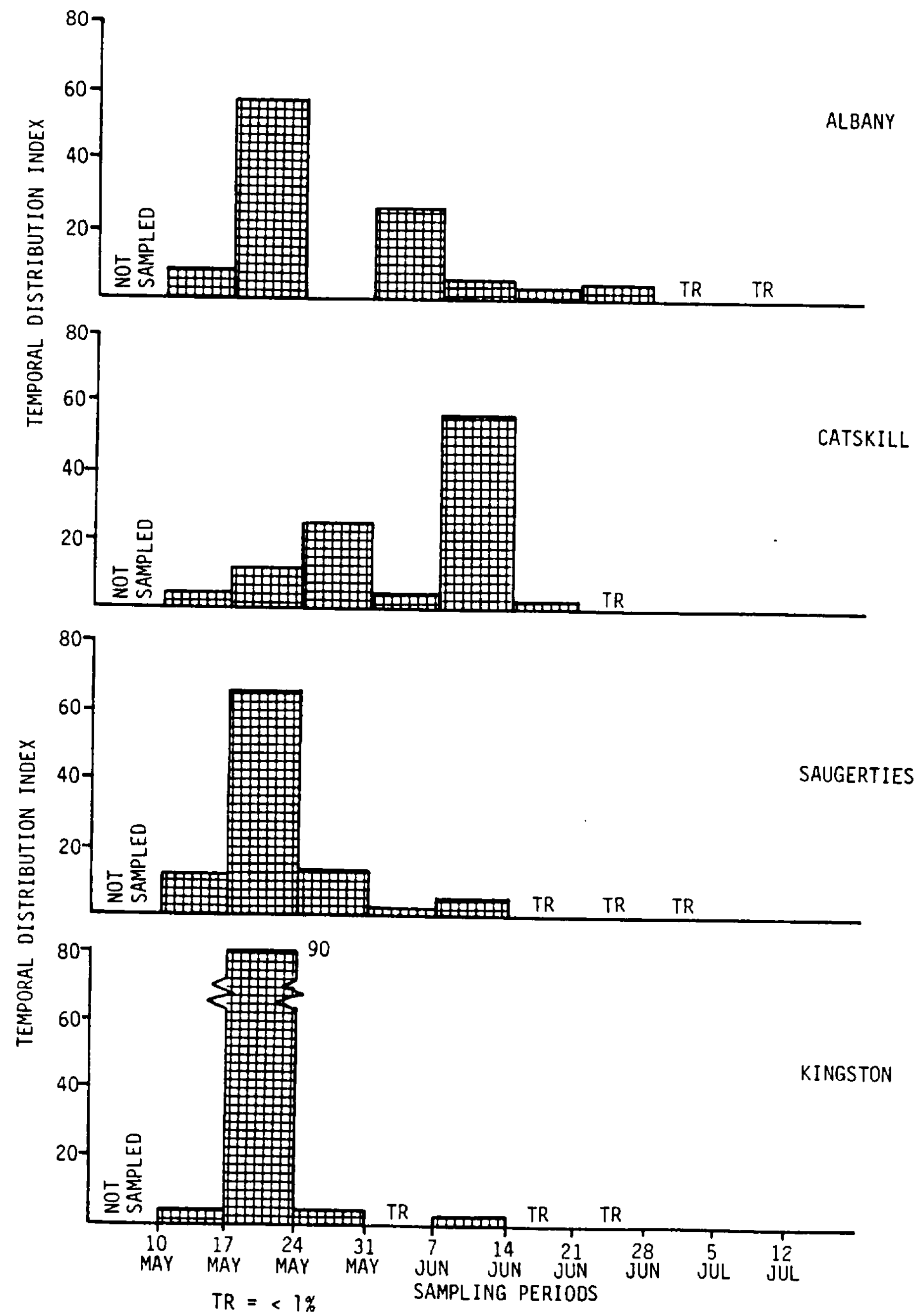


Figure 4.5-4. Temporal distribution of unidentified clupeid yolk-sac larvae, in the regions of peak abundance, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

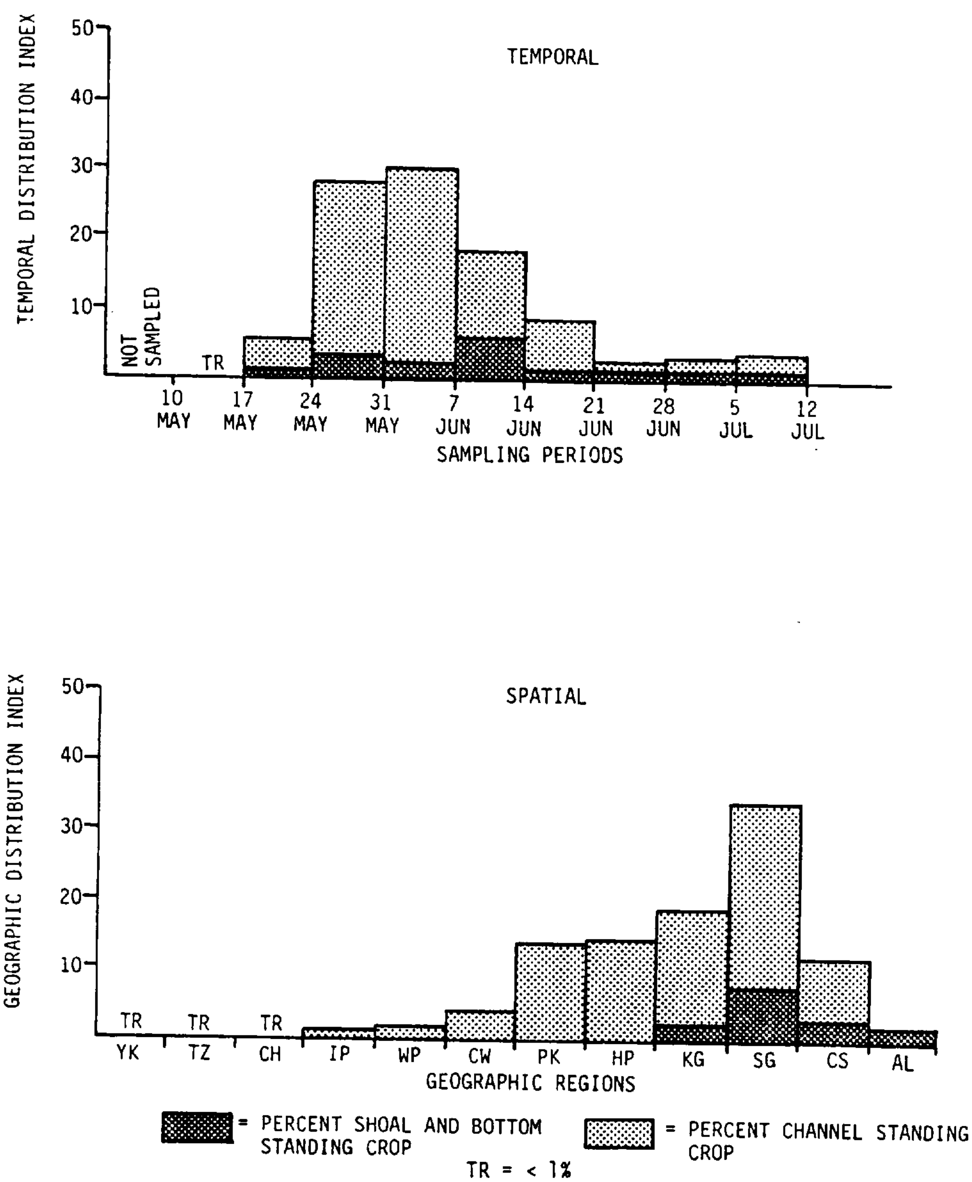


Figure 4.5-5. Patterns in distribution of unidentified clupeid post yolk-sac larvae, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

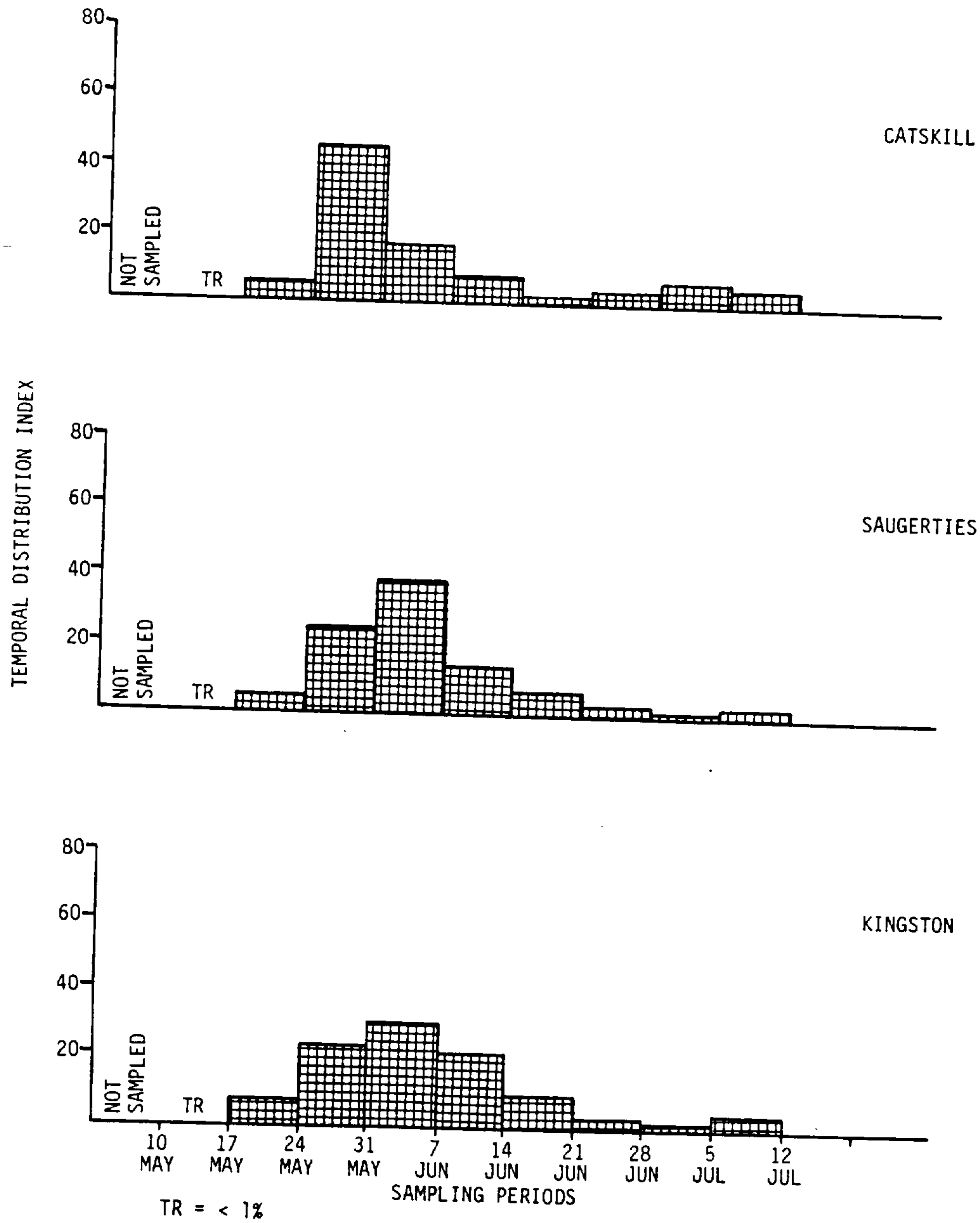


Figure 4.5-6. Temporal distribution of unidentified clupeid post yolk-sac larvae in the regions of peak abundance, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

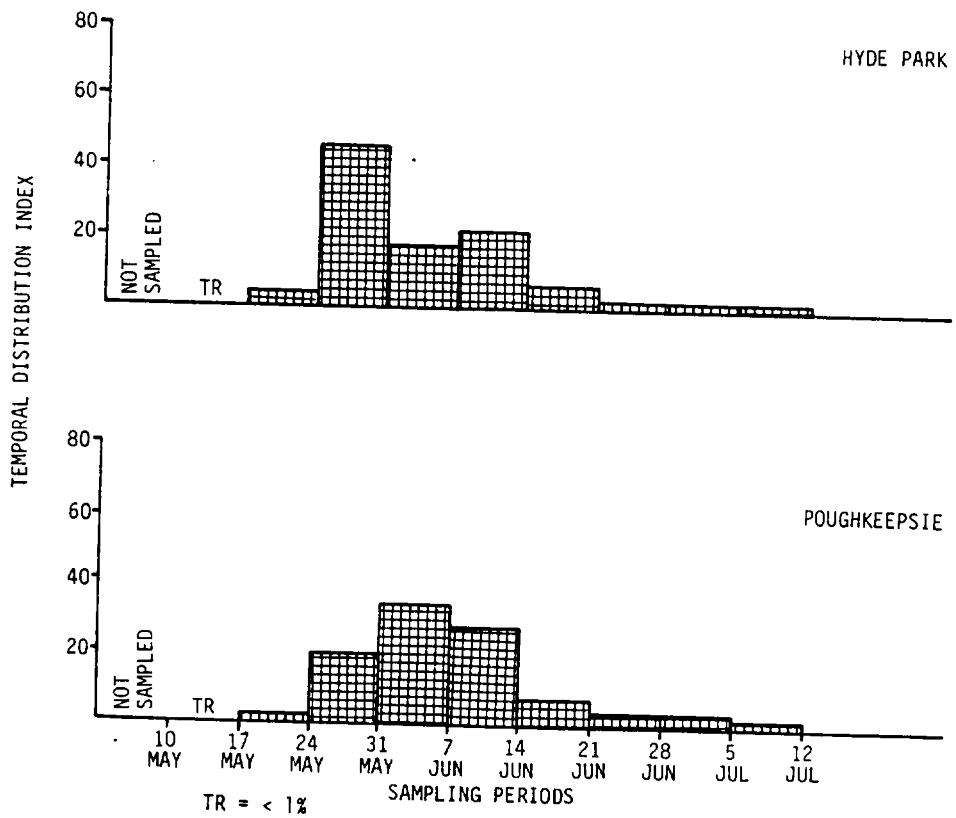


Figure 4.5-6. (continued)

during the last sampling period of the survey (Figure 4.5-7). Although standing crop was highest in the Saugerties region, downriver dispersion was clearly evident.

4.6 BLUEBACK HERRING

Blueback herring (*Alosa aestivalis*) are anadromous, occurring along the east coast in abundance from southern New England to Florida (Bigelow and Schroeder, 1953). As noted previously, their peak spawning migration occurs later in the spring than that of the alewife, although some overlap at the end of the alewife spawning run does occur. Blueback herring enter spawning areas when temperatures are as low as 12.8°C and prefer spawning in fast-moving water over hard substrate (Loesch and Lund, 1977). In large rivers such as the Hudson, they can be found as far upstream as alewives; however, blueback herring do not travel as far up the smaller tributaries as do alewives (Loesch and Lund, 1977). In the Hudson River estuary, most spent adults return to sea by mid-July to mid-August (TI, 1981).

Blueback herring eggs are demersal and somewhat adhesive. Incubation time is 3 to 4 days at 20° to 21°C (Jones *et al.*, 1978). Juvenile blueback herring apparently do not begin to emigrate from the nursery grounds in the Hudson River estuary until mid-October (TI, 1981).

4.6.1 Young-of-the-Year (>35-40 mm)

As noted previously, blueback herring juveniles are indistinguishable from those of alewife until they reach approximately 35-40 mm (total length). In 1982, two identifiable juveniles were collected in ichthyoplankton samples in early July. In the Fall Shoals survey, blueback herring juveniles were most abundant at the start of sampling in early August (Figure 4.6-1). Juveniles were concentrated in the bottom strata of the upriver regions from Cornwall to Albany. By early

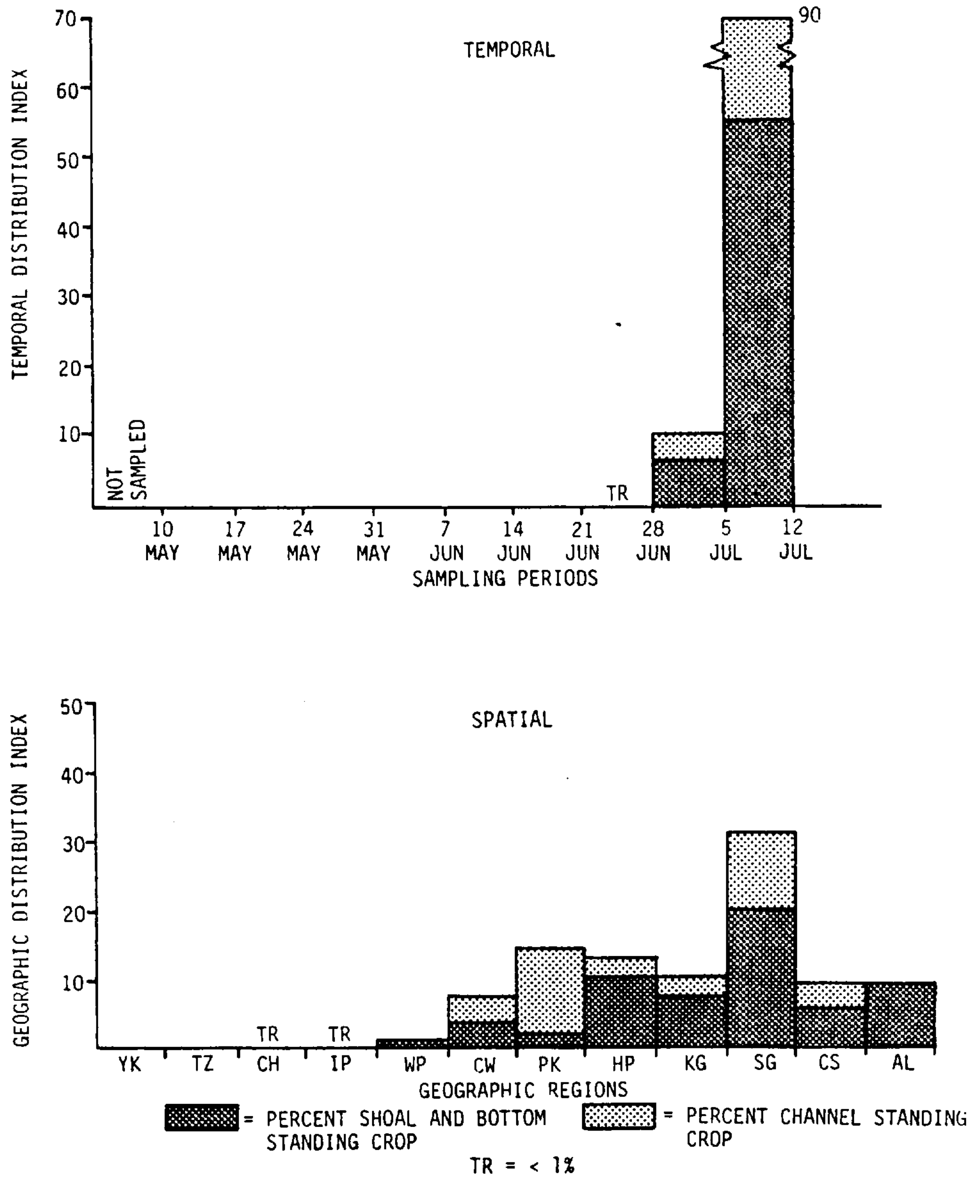


Figure 4.5-7. Patterns in distribution of unidentified clupeid young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

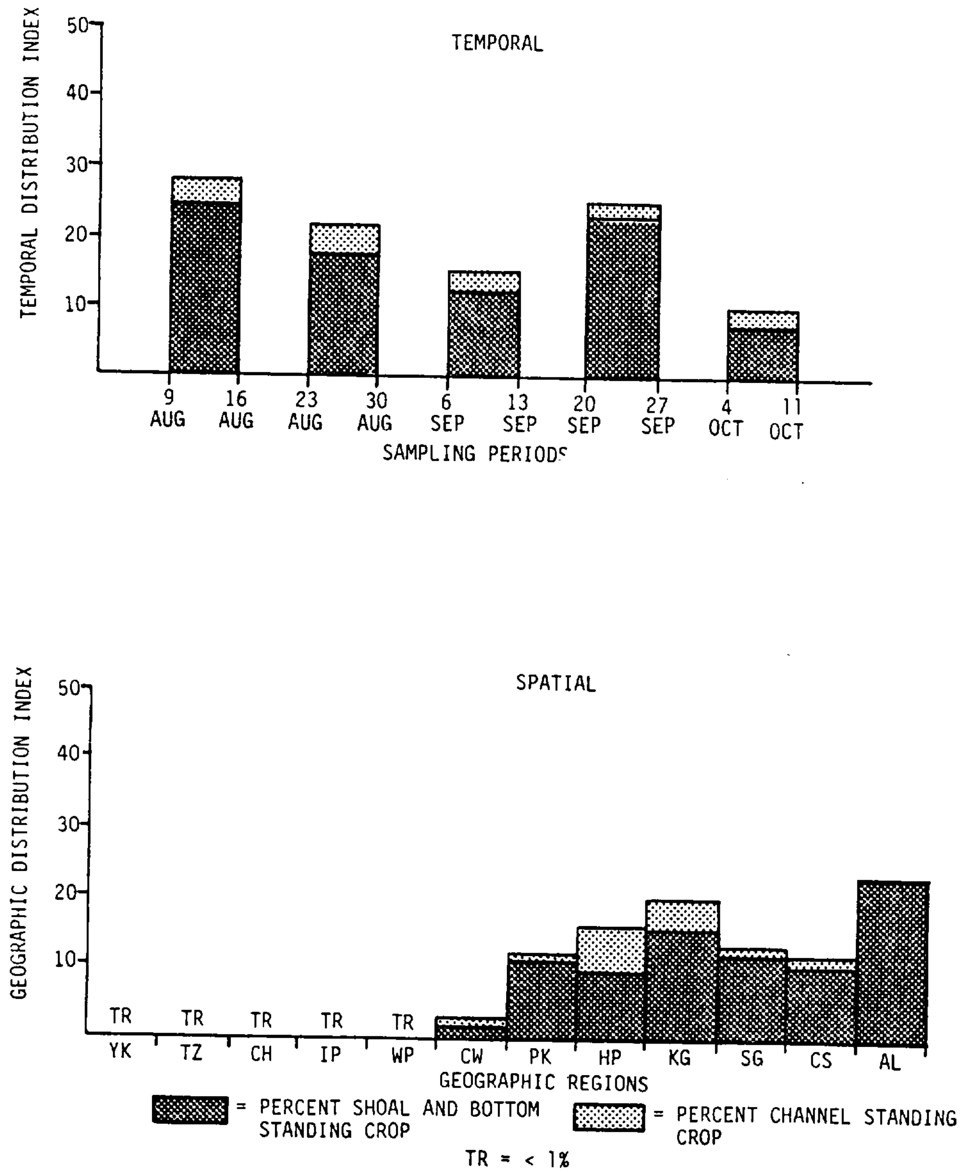


Figure 4.6-1. Patterns in distribution of blueback herring young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals sampling).

October, standing crop in the offshore strata had declined somewhat (Figure 4.6-1).

In the shore zone, blueback herring juveniles reached peak levels in early September (Figure 4.6-2). Highest standing crop occurred in the Poughkeepsie and Saugerties regions. By early October, standing crop in the shore zone had also declined from peak levels.

Spatial and temporal distribution of blueback herring juveniles in 1982 was generally similar to that reported in previous years for comparable time periods (TI, 1981; Battelle, 1983). Juveniles have been abundant in the upper and middle estuary throughout the summer. Emigration reportedly does not begin until mid-October; in 1979, emigration occurred when water temperatures dropped below 14°C (TI, 1981). In 1982, when sampling ended in early October, water temperatures were above 18°C throughout the estuary.

4.6.2 Yearling and Older Fish

Yearling and older blueback herring were collected sporadically and in very low numbers during 1982 (Appendix B, Tables B-44, B-45 and B-46). No conclusions could be drawn regarding distribution.

4.7 ALEWIFE

The alewife, *Alosa pseudoharengus*, is an anadromous fish occurring along the east coast from the Gulf of St. Lawrence south to South Carolina (Leim and Scott, 1966). Spawning migrations occur in spring, with temperature being the most important environmental variable influencing entrance to the spawning grounds (Richkus, 1974). Alewives prefer to spawn in relatively shallow, sluggish water over soft substrates (Bigelow and Schroeder, 1953; Kissil, 1974). Following spawning, spent adults apparently emigrate from the Hudson River by mid-June (TI, 1981).

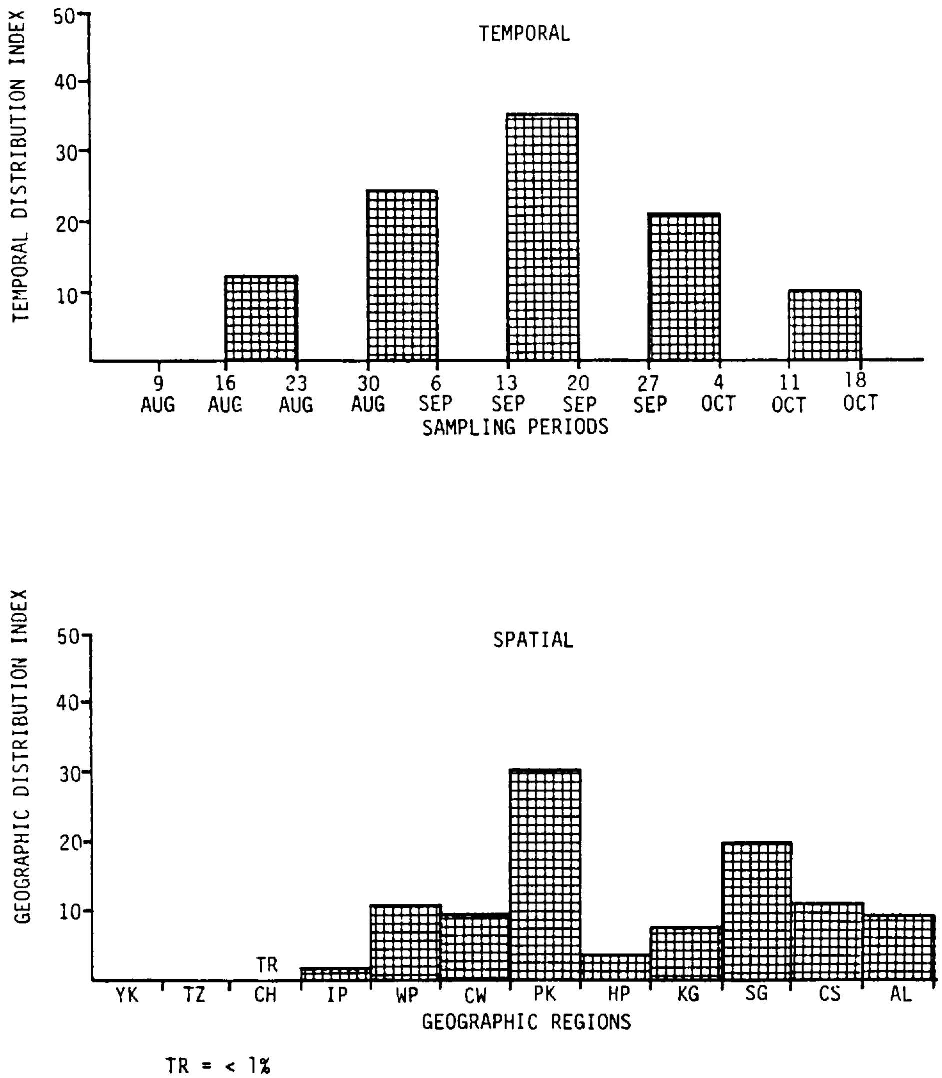


Figure 4.6-2. Patterns in distribution of blueback herring young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine sampling).

Alewife eggs are demersal and semi-adhesive; hatching occurs in 6 days at 15.6°C (Mansueti and Hardy, 1967). Optimum incubation temperatures of 17.8°C have been reported (Edsall, 1970). Emigration of juveniles occurs throughout the summer, with the majority of juveniles having left the spawning grounds by autumn (Bigelow and Schroeder, 1953).

4.7.1 Young-of-the-Year (>35-40 mm)

Identifiable juvenile alewives were first collected during the last ichthyoplankton sampling period in early July; most were found in the Saugerties area (Figure 4.7-1). Juvenile alewives collected in the Fall Shoals survey were most abundant in late August and late September. By early October, standing crop had declined to very low levels. Juveniles were concentrated in the upper and middle estuary in the offshore strata with peak standing crop in the Hyde Park and Kingston regions (Figure 4.7-2).

Shore zone abundances also reached a peak in late August (Figure 4.7-3). As juvenile abundances declined in the offshore strata in early October, an increase was observed in the shore zone. In the shore zone, alewife juveniles were more abundant in the lower and middle estuary, whereas in the offshore strata, they were more abundant in the upper estuary (Figures 4.7-2 and 4.7-3). It appears that an increase in downstream movement began in early October. Alewife juveniles reportedly begin moving downriver into the middle and lower estuary early in the summer, with increased downriver movements evident in October and November coincident with declining water temperatures and increasing freshwater flows (TI, 1981).

4.7.2 Yearling and Older Fish

In the offshore strata, alewife yearlings were most abundant in the channel in early August (Figure 4.7-4), primarily due to a peak

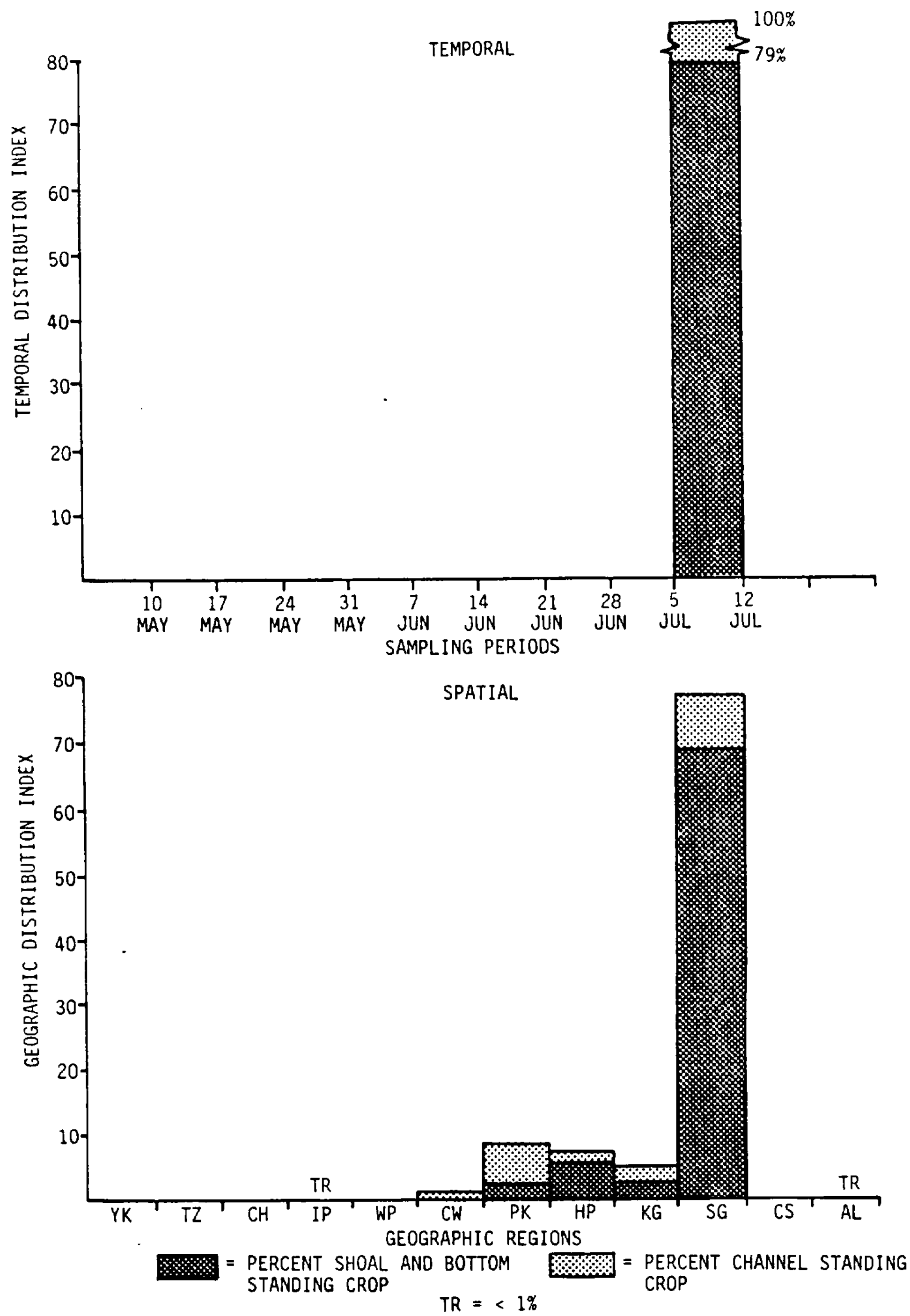


Figure 4.7-1. Patterns in distribution of alewife young-of-the-year, Hudson River estuary, 1982 (based on ichthyoplankton sampling).

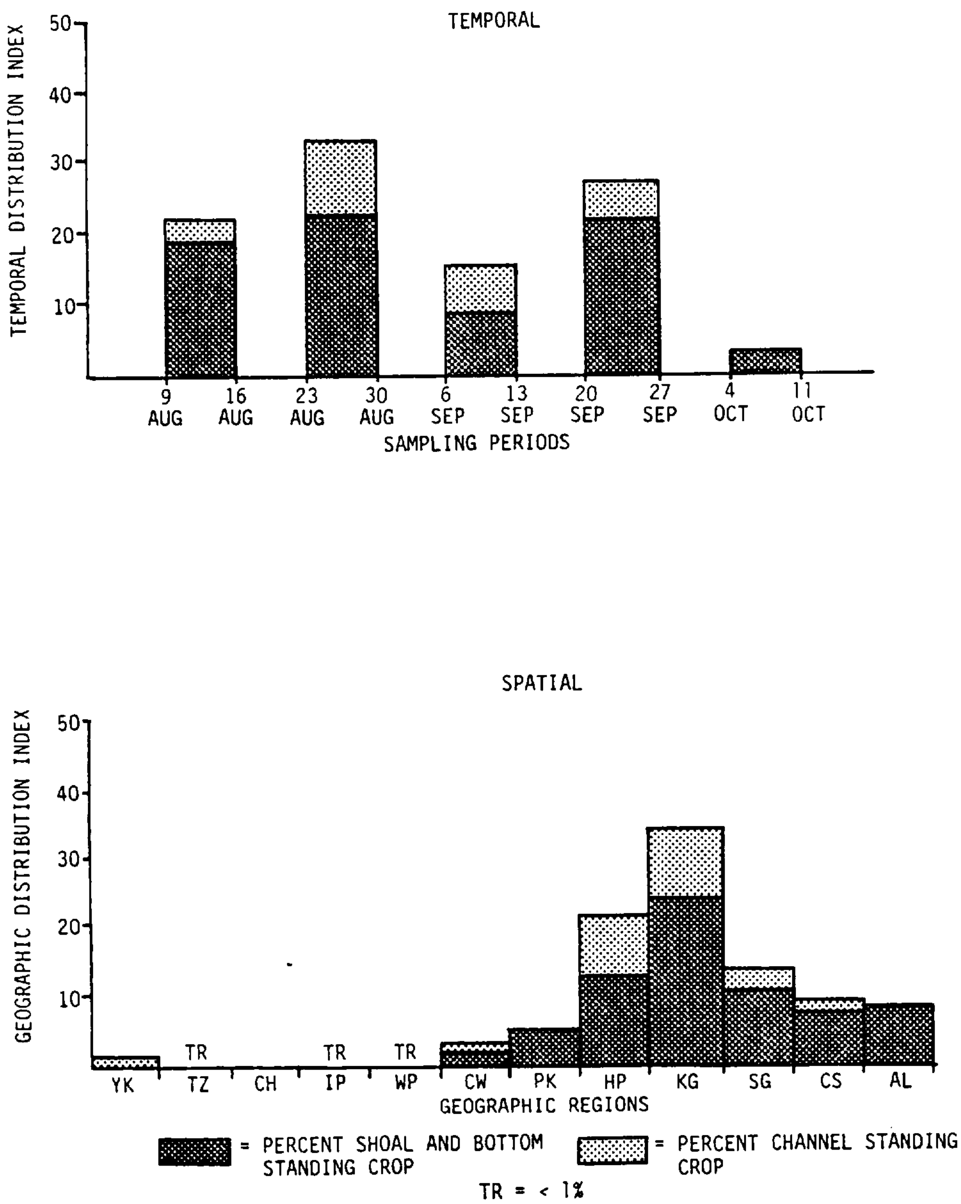


Figure 4.7-2. Patterns in distribution of alewife young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals sampling).

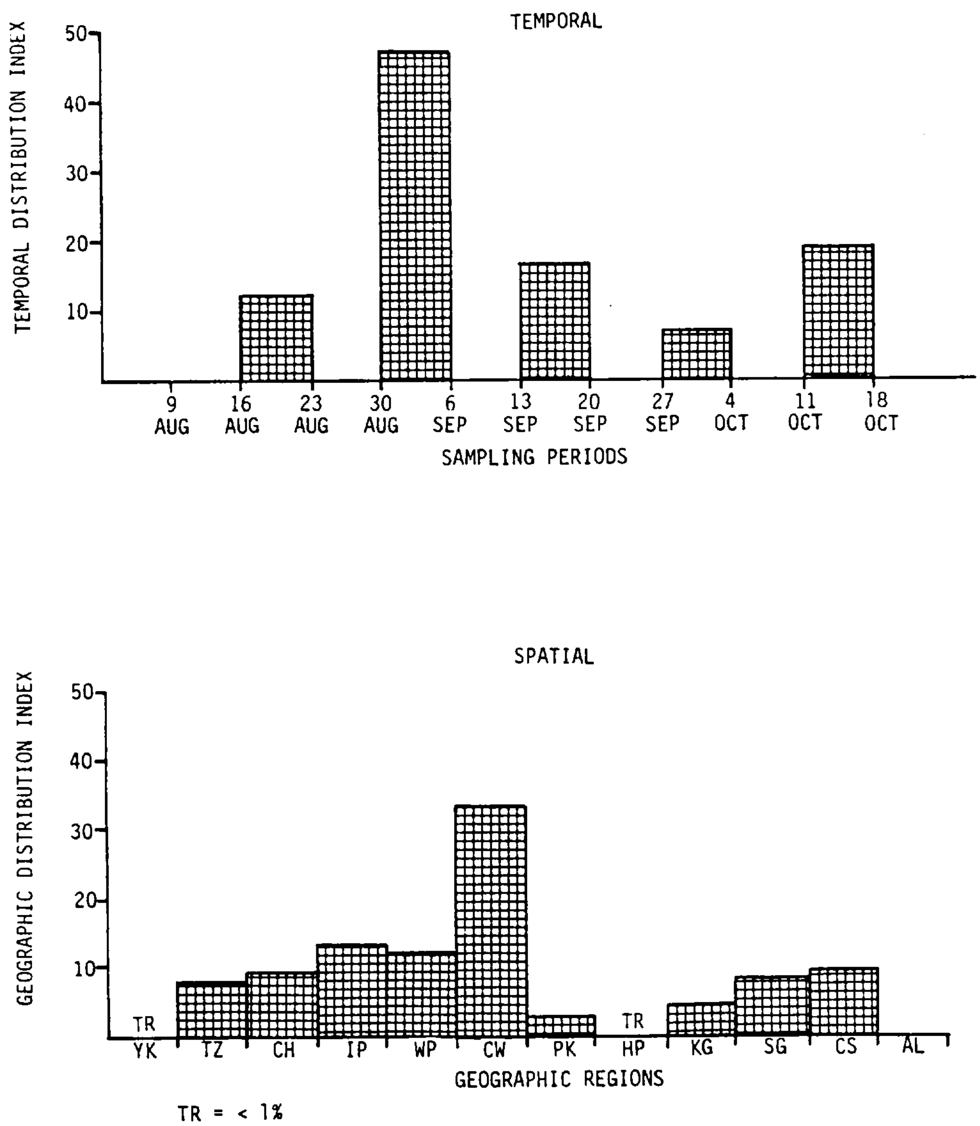


Figure 4.7-3. Patterns in distribution of alewife young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine sampling).

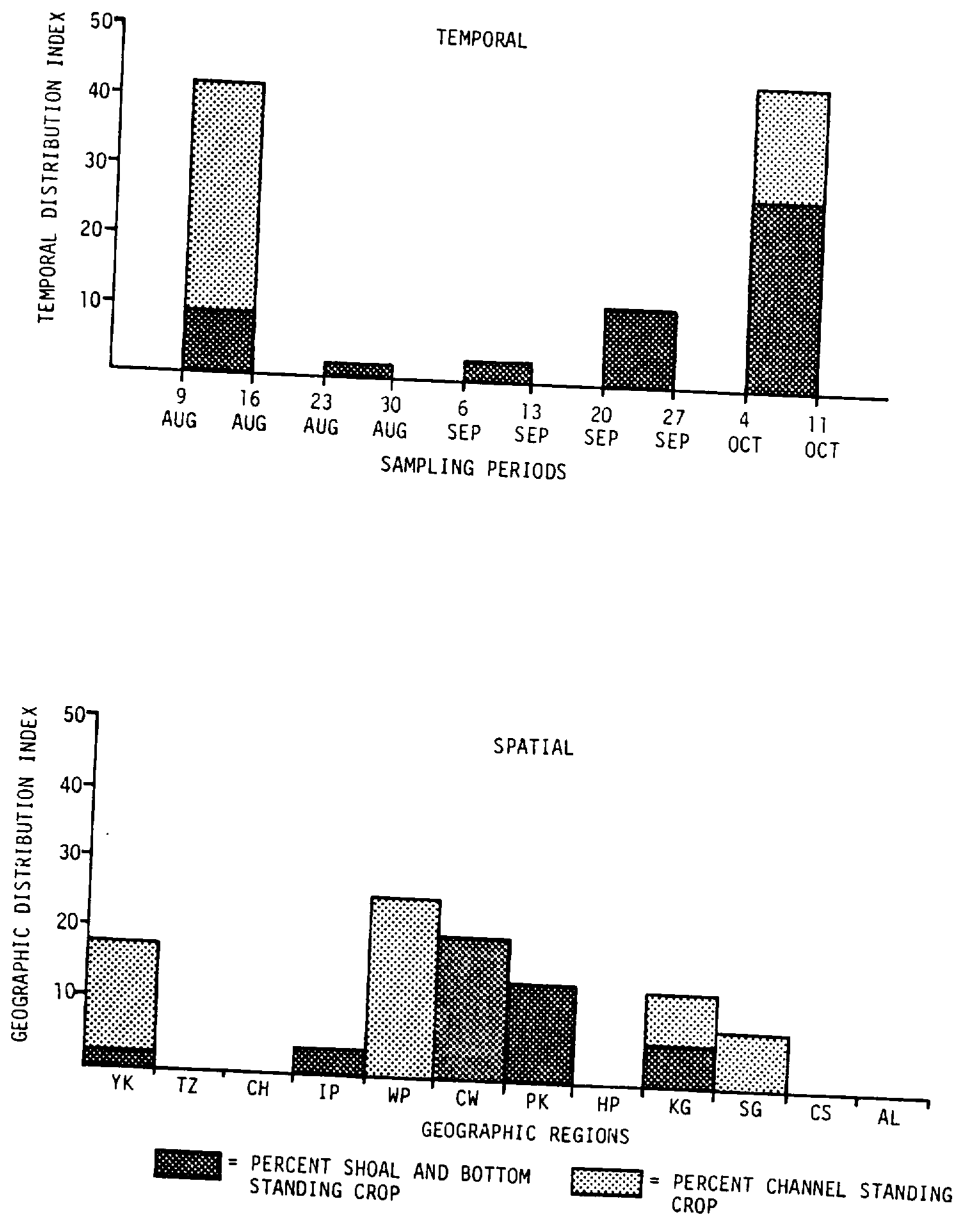


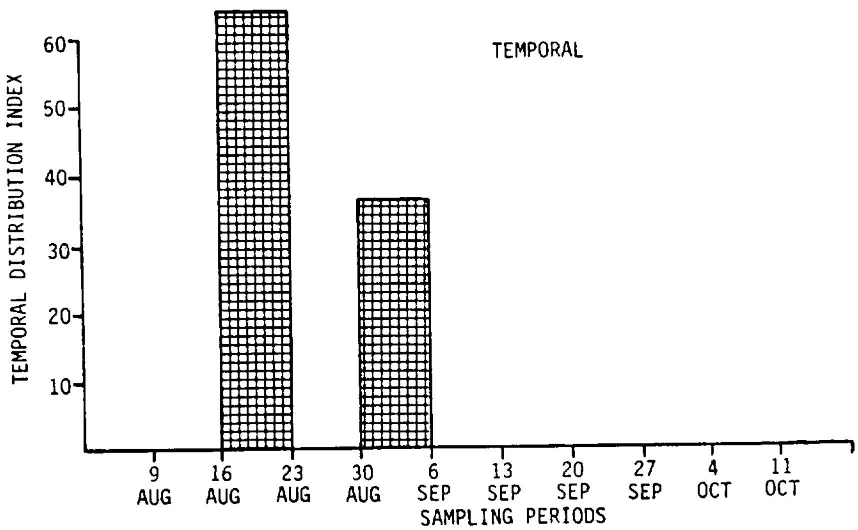
Figure 4.7-4. Patterns in distribution of alewife yearlings, Hudson River estuary, 1982 (based on Fall Shoals sampling).

in standing crop in the West Point area (Appendix B, Table B-49). Standing crop declined during the last sampling period in August, and subsequently increased to a second peak in early October. Temporal differences by region were apparent (Appendix B, Table B-49). In the upper estuary, almost all yearlings were collected in early August, while in the middle estuary, standing crop peaked in late September and early October (except at West Point). In the lower estuary, virtually all yearlings found occurred at Yonkers in early October. These spatiotemporal trends indicate the passage of yearlings downstream during the summer. Standing crop in the shore zone was minimal (Appendix B, Table B-50); the few fish caught occurred in the lower estuary in August (Figure 4.7-5). No alewives older than yearling were collected during this study.

4.8 BAY ANCHOVY

The bay anchovy (*Anchoa mitchilli*) is one of the most abundant fishes of the Atlantic coast (Massman, 1953; Dahlberg, 1972; Derickson and Price, 1973). It occurs in coastal waters from Cape Cod (occasionally into the Gulf of Maine) and southward to Yucatan, Mexico (Hildebrand, 1963). The bay anchovy feeds on mysid shrimp and copepods (Richards, 1963) and in turn is utilized as forage by many fish species including economically important fishes such as white perch, striped bass and bluefish.

Bay anchovies undergo inshore/offshore movements apparently related to spawning and maturation. In the Hudson River estuary, yearling and presumably some older bay anchovy move upstream during May to feed in the brackish waters as far north as Poughkeepsie (Dovel, 1981). When water temperatures rise above 12°C, mature individuals move back downstream from the low saline nursery area into higher salinity waters (>10 $^{o}/oo$) to spawn (Dovel, 1981). Spawning is concentrated in the river from Tappan Zee south to the Narrows as evidenced by peak egg abundance in this location, and particularly in Yonkers (Dovel, 1981; TI, 1981). Peak spawning occurs during July at temperatures greater



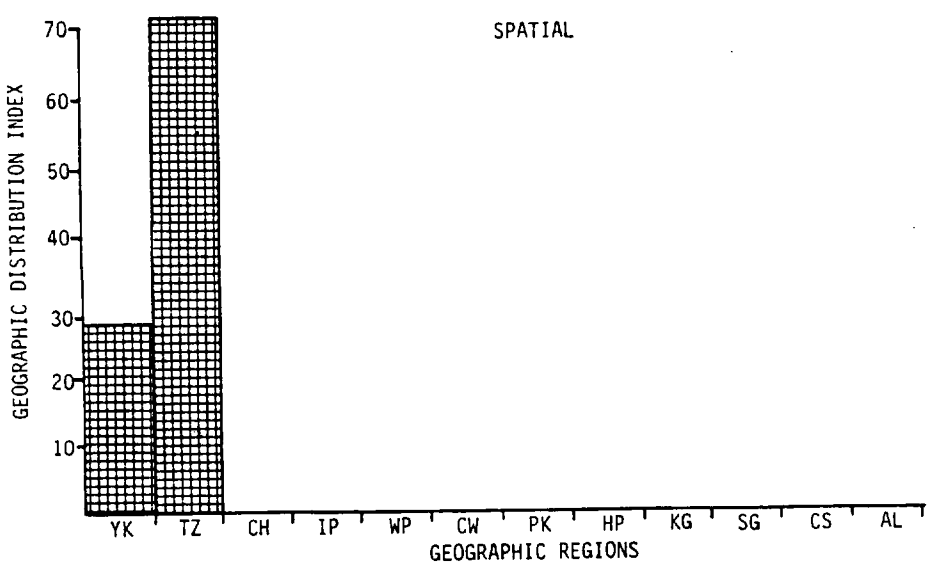


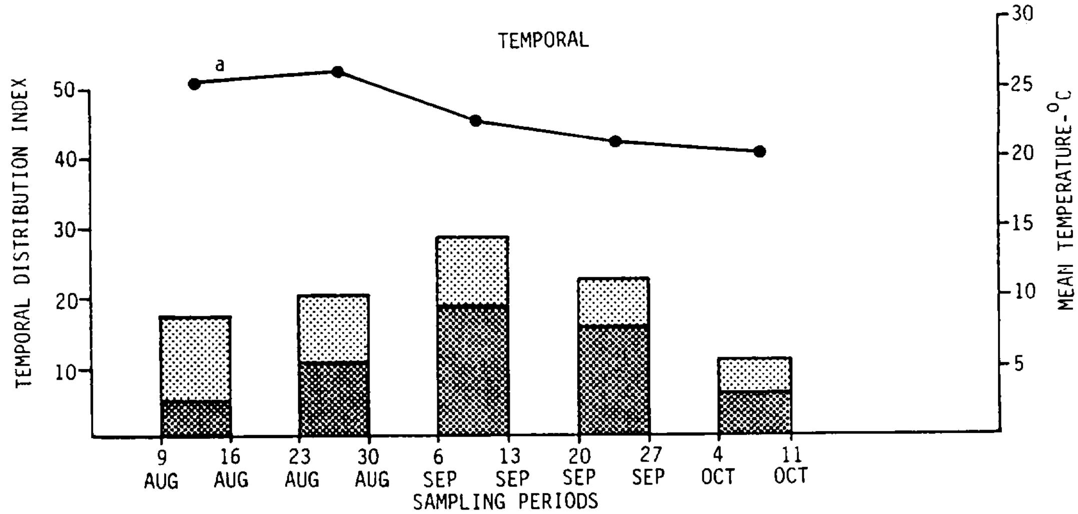
Figure 4.7-5. Patterns in distribution of alewife yearlings, Hudson River estuary, 1982 (based on Beach Seine sampling).

than 20^{o}C and the newly-hatched larvae move upstream into the lower salinity waters (<10 ^{o}/oo) of the Tappan Zee through Indian Point regions to feed. By early fall, larvae and young-of-the-year move downstream out of the low salinity nursery area. Similar trends were reported for bay anchovy in several Chesapeake areas (Dovel, 1971; Lippson *et al.,* 1980) and were described for the Japanese anchovy by Asami (1958) and Hayusi (1961) (cited in Dovel, 1981). By late November, anchovies have emigrated from most of the Hudson River estuary to their overwintering grounds.

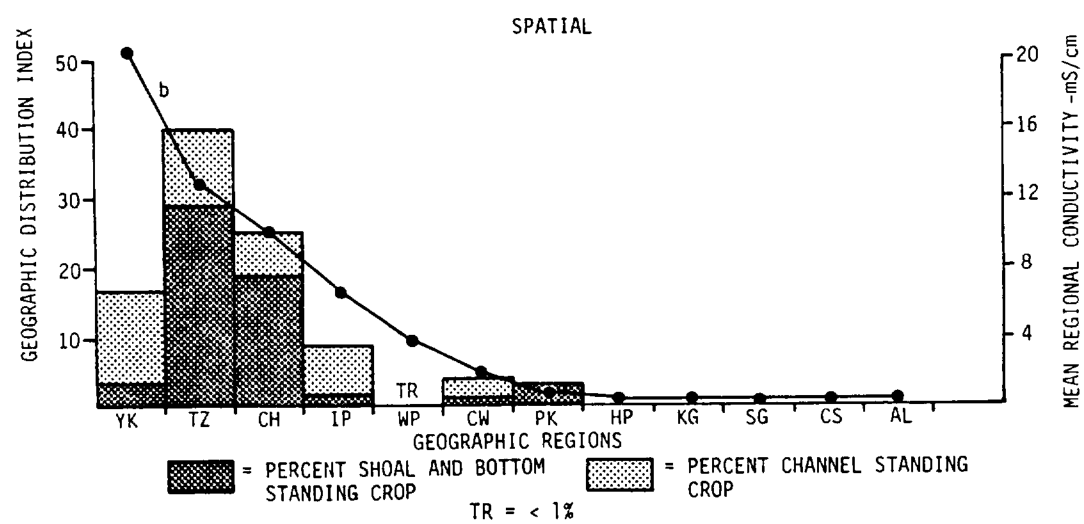
Dovel (1981) proposed that bay anchovies require a definite period of exposure to the brackish water environment before reaching maturity and that their downstream movement in spring and fall is related to the onset of maturity. Fish spawned early in the year begin a permanent downstream movement once maturity is reached during early fall and do not return to the upriver nursery area the following spring. Fish spawned late in the year might be forced from the estuary by declining temperatures before maturity was reached. The following spring, these immature yearlings would migrate back to the low salinity nursery area to feed, and once mature, move back down river to spawn.

4.8.1 Young-of-the-Year

Juvenile bay anchovy were first observed during the last sampling period of the ichthyoplankton survey (5 July 1982). During this period, they were detected only in the shoal stratum of the Croton-Haverstraw region (standing crop = 1.3 x 10^6 fish). Earlier surveys reported recruitment to the juvenile stage in late June/early July and peak abundances of juveniles from mid-July through September (TI, 1981; Battelle, 1983). Young-of-the-year bay anchovy were present through the course of the Fall Shoals and Beach Seine surveys from Yonkers to Poughkeepsie (Figures 4.8-1 and 4.8-2). Abundances were highest in Tappan Zee and decreased upriver from this region with decreasing conductivity values below 12 mS/cm. Juveniles were absent from waters with a conductivity of less than 0.5 mS/cm (i.e., Hyde Park to Albany).



[a] MEAN TEMPERATURE OF THE OFFSHORE STRATA IN THE POUGHKEEPSIE THROUGH ALBANY REGIONS



[b] MEAN CONDUCTIVITY OF THE OFFSHORE STRATA BY REGION FROM 9 AUGUST THROUGH 11 OCTOBER

Figure 4.8-1. Patterns in distribution of bay anchovy young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals survey).

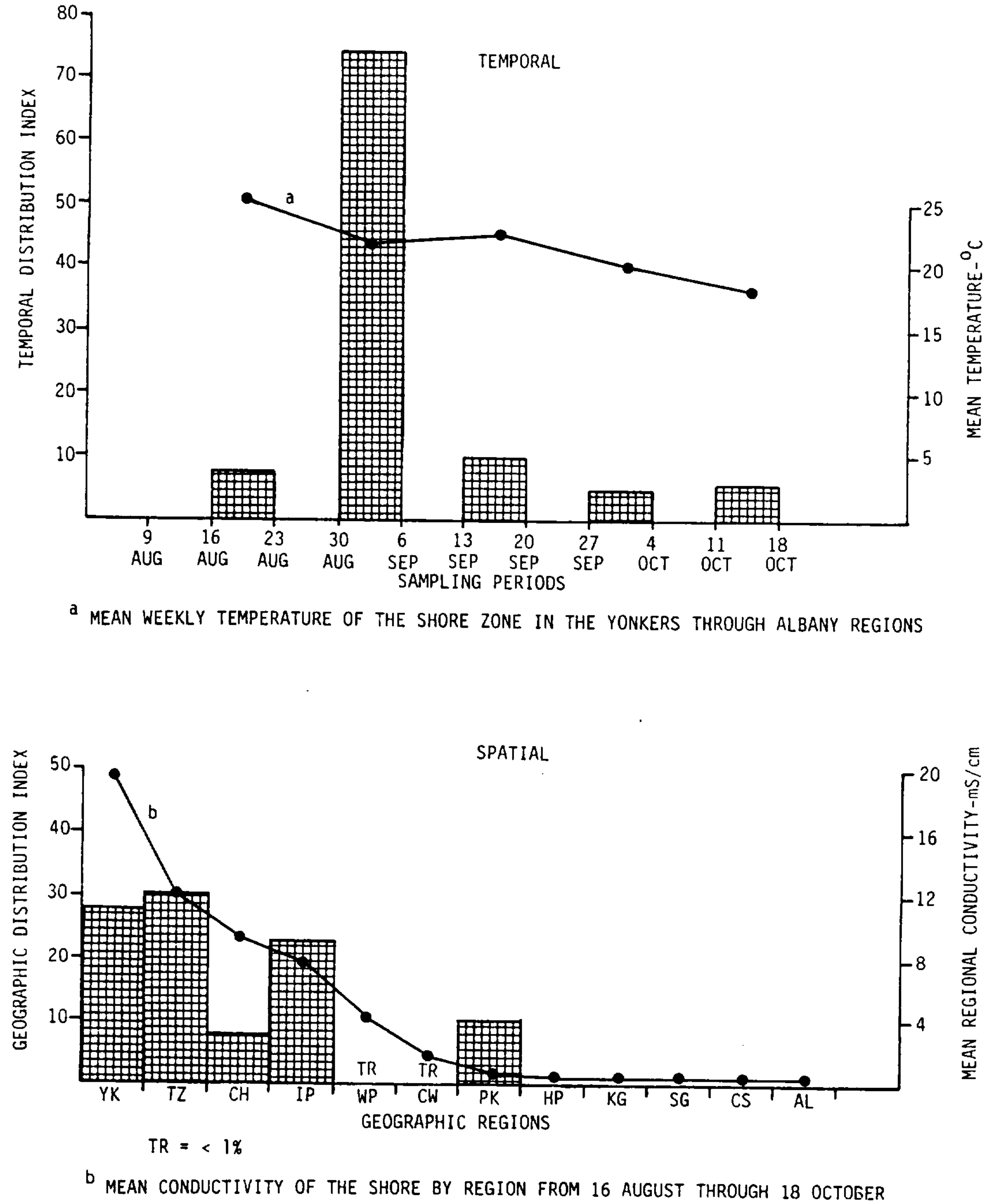
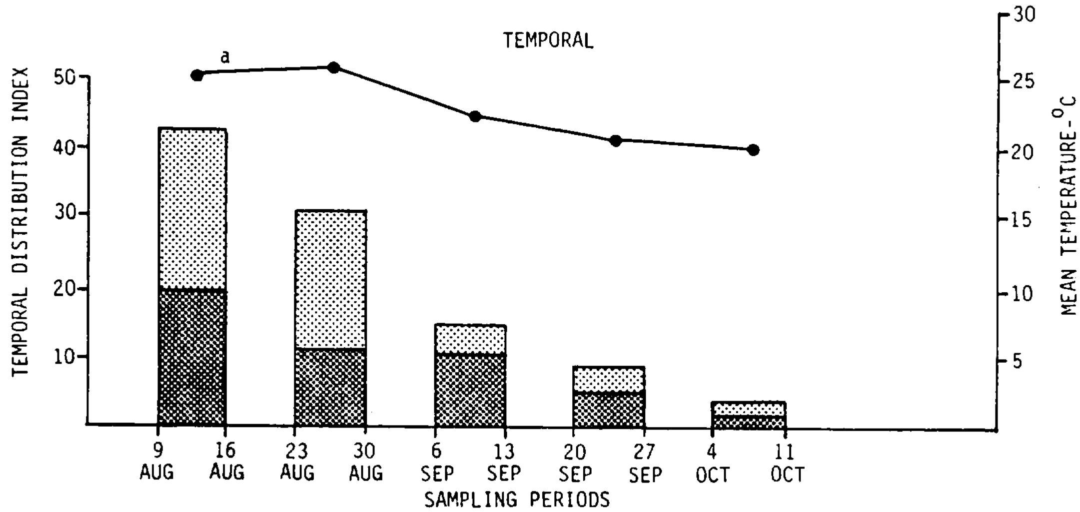


Figure 4.8-2. Patterns in distribution of bay anchovy young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine survey).

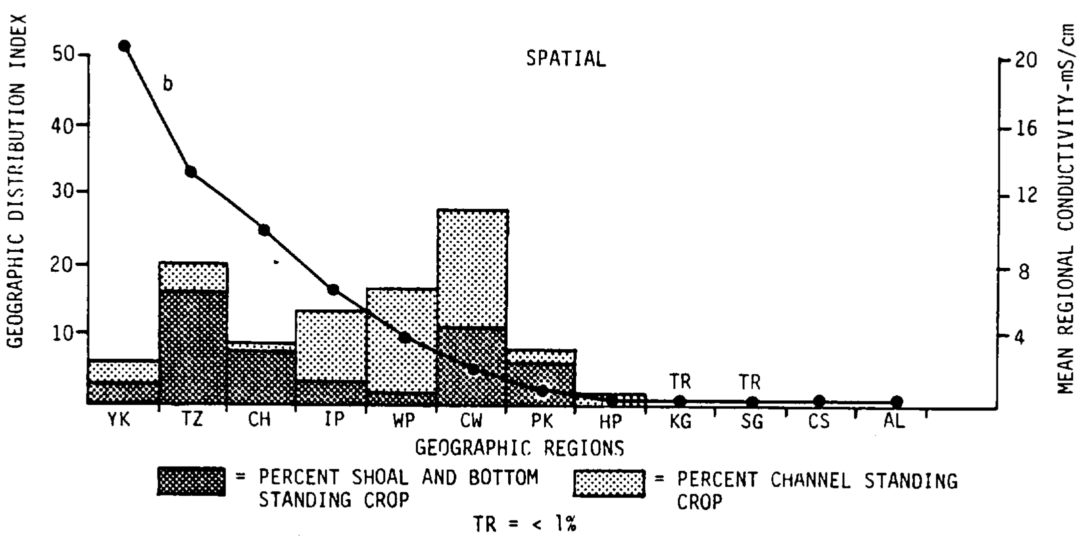
In both the shore zone and offshore strata, standing crop was highest during late August and early September at temperatures of approximately 22°C. Following these peaks, abundances steadily declined and reached the lowest levels of both surveys during October at temperatures of approximately 18°C-20°C. Past surveys detected peaks in juvenile abundance during August in the middle estuary, followed by a downstream movement and a peak in the lower estuary during early to mid-September (TI, 1981). Emigration of juvenile bay anchovy from the estuary has been observed to begin near the end of September with most of the juvenile population absent from the estuary by November.

4.8.2 Yearling and Older Fish

All adult bay anchovies collected during 1982 were yearlings. Standing crop of bay anchovy yearlings was highest during the first sampling periods of both the Fall Shoals (9 August) and Beach Seine (16 August) surveys (Figures 4.8-3 and 4.8-4). Subsequently, standing crop declined in the offshore strata and the shore zone as well, although shore zone standing crop was somewhat variable. Past years' reports described movement of adults into the Hudson River during early to late May, and peak abundances during late May through July (TI, 1981; Battelle, 1983). Offshore and downstream movements typically began in late July and most adults had left the study area by late October. In 1982, yearling bay anchovies were concentrated more upriver in the offshore strata than juveniles, but like juveniles, they did not extend beyond the salt front located in the Poughkeepsie/Hyde Park region (Figure 4.8-3). The greatest proportion of yearlings occurred at Cornwall compared to highest concentrations of juveniles further downriver in Tappan Zee. As in past years, yearling bay anchovies collected in the shore zone were concentrated primarily in the Yonkers, Tappan Zee and Indian Point regions. Only a small proportion was detected in the shore zone of Croton-Haverstraw, and none were detected onshore above Indian Point.



a MEAN TEMPERATURE OF THE OFFSHORE STRATA IN THE YONKERS THROUGH POUGHKEEPSIE REGIONS



b MEAN CONDUCTIVITY OF THE OFFSHORE STRATA BY REGION FROM 9 AUGUST THROUGH 11 OCTOBER

Figure 4.8-3. Patterns in distribution of bay anchovy yearling, Hudson River estuary, 1982 (based on Fall Shoals survey).

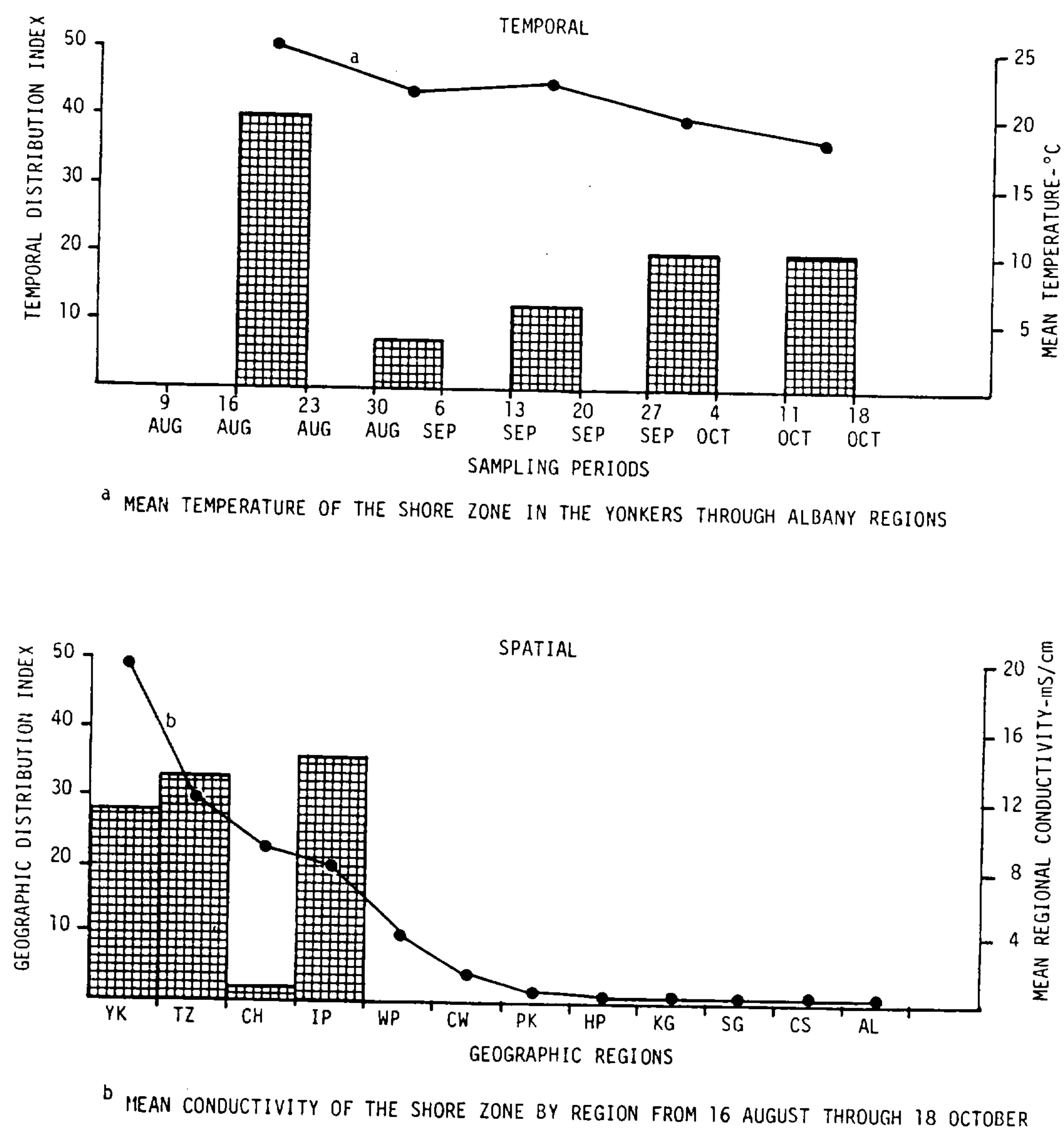


Figure 4.8-4. Patterns in distribution of bay anchovy yearling, Hudson River estuary, 1982 (based on Beach Seine survey).

4.9 WEAKFISH

The weakfish, *Cynoscion regalis* (Bloch and Schneider), a member of the family Sciaenidae, is an important commercial and recreational fish of the Atlantic coast (Wilk, 1979). The weakfish ranges from the east coast of Florida to Massachusetts Bay. At one time, large numbers of weakfish were reported as far north as Nova Scotia (Bigelow and Schroeder, 1953) but only a few individuals are present there today. The area of greatest abundance centers around the waters of the Chesapeake Bay region (Thomas, 1971). In the Hudson River, weakfish are found as far upriver as Hyde Park (RM 86), with the area of greatest concentration in the lower reaches of the estuary (RM 0-55).

Adult weakfish are euryhaline, but only the smaller juveniles have been collected in fresh and low-salinity waters (Smith, 1971; Thomas, 1971). Spawning is preceded by an upriver migration which is triggered by increases in water temperatures. Spawning begins during late May and continues through September (Bigelow and Schroeder, 1953; Lippson and Moran, 1974), with major peaks occurring during early June and July (Thomas, 1971; Johnson, 1978). Spawning takes place over a broad temperature range (15^{o}-21^{o}C) in areas where salinity varies between 28 and 31 $^{o}/oo$ (Lippson and Moran, 1974). Both sexes mature at age III, and larger females may produce several million eggs (TI, 1981). After spawning, weakfish move out of the estuaries and overwinter off the coast of the Carolinas (Bigelow and Schroeder, 1953).

Weakfish eggs are pelagic and highly buoyant (Lippson and Moran, 1974), becoming heavier with development. The eggs are spherical and transparent, with a mean diameter of 0.84-1.3 mm, and decrease in size with increasing salinity (Johnson, 1978). The eggs are usually found in areas having water temperatures of 17-26.5^{o}C and salinities of 12-31 $^{o}/oo$. They hatch in about 40 hrs at 20-21^{o}C (Harmic, 1958). The newly-hatched larvae are 1.5-2.0 mm TL and yolk absorption occurs at approximately 2.2 mm TL. The larvae generally sink to the bottom allowing the bottom currents to carry them upstream (Thomas, 1971).

Juveniles tend to occupy the deeper shoal and channel waters of the low salinity areas (Smith, 1971). In Delaware Bay, young weakfish were most abundant in the lower salinity waters (3-6 $^{o}/oo$) with lower frequencies occurring in freshwater as well as in higher saline areas (Thomas, 1971). Very little information is available on the lower limit of the temperatures preferred by weakfish. They appear to be sensitive to the cold, as the autumn seasonal chilling seems to be responsible for their southerly movement out of the estuaries.

4.9.1 Young-of-the-Year

When the Fall Shoals sampling program began in early August, juvenile weakfish were already at or past the period of maximum abundance (Figure 4.9-1). They occurred primarily in the deeper areas of the lower and middle estuaries. Average temperatures during this time period were 25.4^{o}C (range 24.4^{o}-25.9^{o}C) and conductivities were 10.7 mS/cm (range 3.1-22.8 mS/cm) (Figure 3.1-1 and 3.3-1; Appendix C, Tables C-1 and C-5). No juveniles were collected upriver of Cornwall (conductivity 0.489 mS/cm), which represented the approximate boundary of the salt front. This spatial distribution was similar to those observed in previous years (TI, 1980b, 1981; Battelle, 1983) and appears to be associated with the patterns of conductivity.

Juvenile weakfish appeared to be emigrating from the offshore strata throughout the August through October sampling season (Figure 4.9-1). This was associated with a decrease in temperatures (24.4-19.6^{o}C) and conductivities (22.8-18.4 mS/cm). Thomas (1971) described a similar decline in abundance in late September to early October in the Delaware River, but speculated that this decline was associated more with mortality than emigration. By the end of September, most of the juvenile weakfish population had left the offshore strata of the Hudson River study area and by October juveniles occurred in only trace abundances.

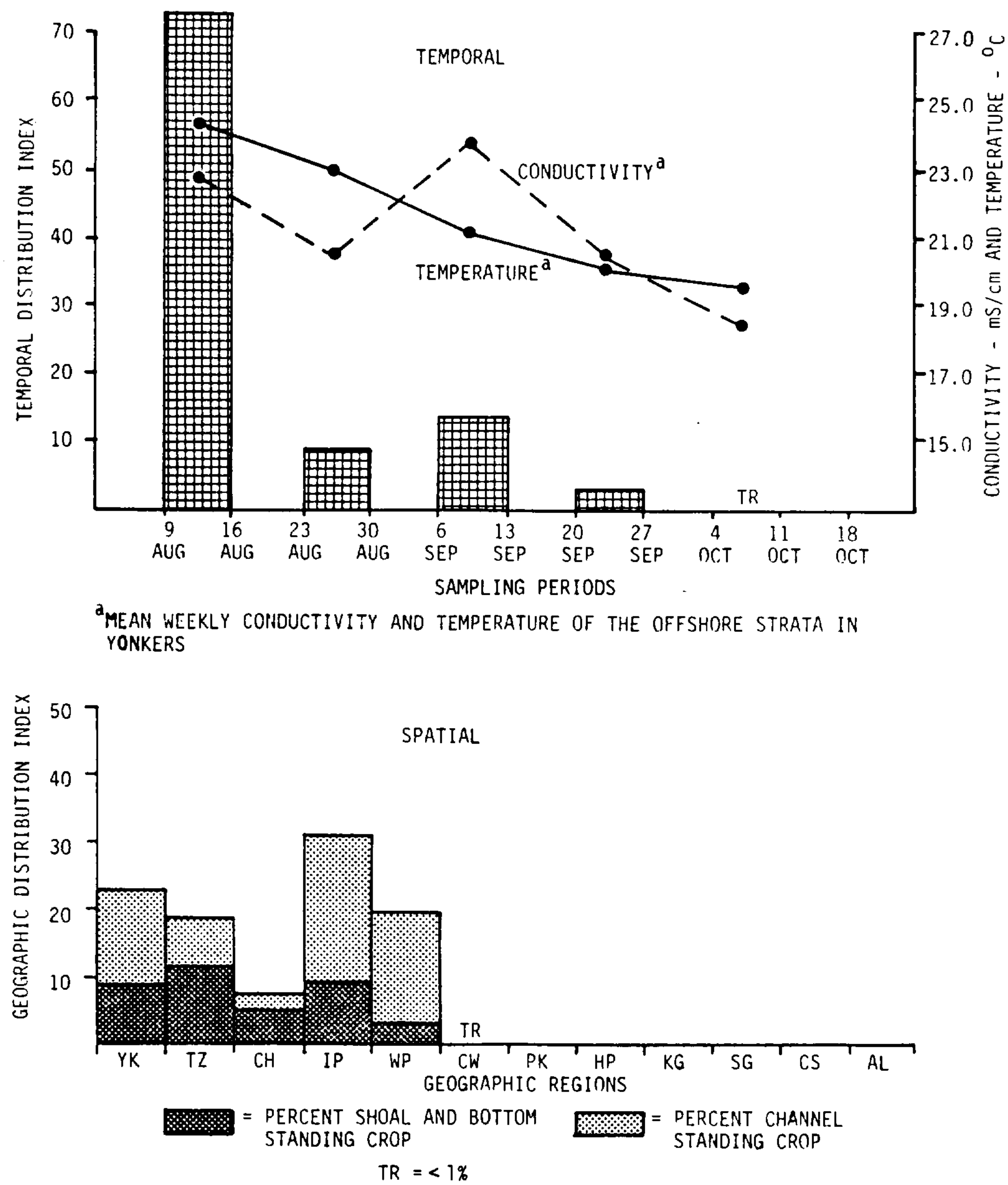


Figure 4.9-1. Patterns in distribution of weakfish young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals sampling).

Weakfish collected in the shore zone also declined in abundance through the last sampling period in October when they comprised only about 10 percent of the total standing crop (Figure 4.9-2). Shore zone catches of weakfish were restricted to the lower two regions, particularly Yonkers. In past years, all juvenile weakfish had left the study area by November when water temperature began to decrease below $10^{o}C$ (TI, 1981). Thomas (1971) reported that juvenile weakfish emigrated from the Delaware River estuary when water temperatures went below 8^{o}-$10^{o}C$.

4.10 WHITE CATFISH

The white catfish (*Ictalurus catus*) is a resident of coastal streams along most of the east coast of the United States (Trautman, 1957). It inhabits fresh and brackish waters, and can tolerate salinity concentrations up to 14 $^{o}/oo$ (Kendall and Schwartz, 1968). Catfishes are omnivorous bottom feeders utilizing fish, invertebrates, plant material and carrion, and are generally most active at night. Spawning takes place in fresh or slightly brackish water (2 $^{o}/oo$ or less; Perry and Avault, 1968), during late spring and early summer (Lippson *et al.,* 1980). The eggs are adhesive and the young are attended by the parents (Breder and Rosen, 1966).

In the Hudson River estuary, white catfish move shoreward during spring from their deep water overwintering areas in the lower and middle estuary. This shoreward movement during spring was also described for white catfish in the Thames (Schmidt, 1971) and Connecticut (Marcy, 1976b) Rivers. Peak catches of adults in the shore zone of the lower estuary and shoal of the middle and upper estuary in June and July appear to represent the major period of spawning (TI, 1981). Because of the invulnerability of white catfish eggs and larvae to the sampling gear used in Hudson River sampling programs, no information is available on their distribution in the estuary. However, considering that spawning is unsuccessful at salinities above 2 $^{o}/oo$ (Perry and

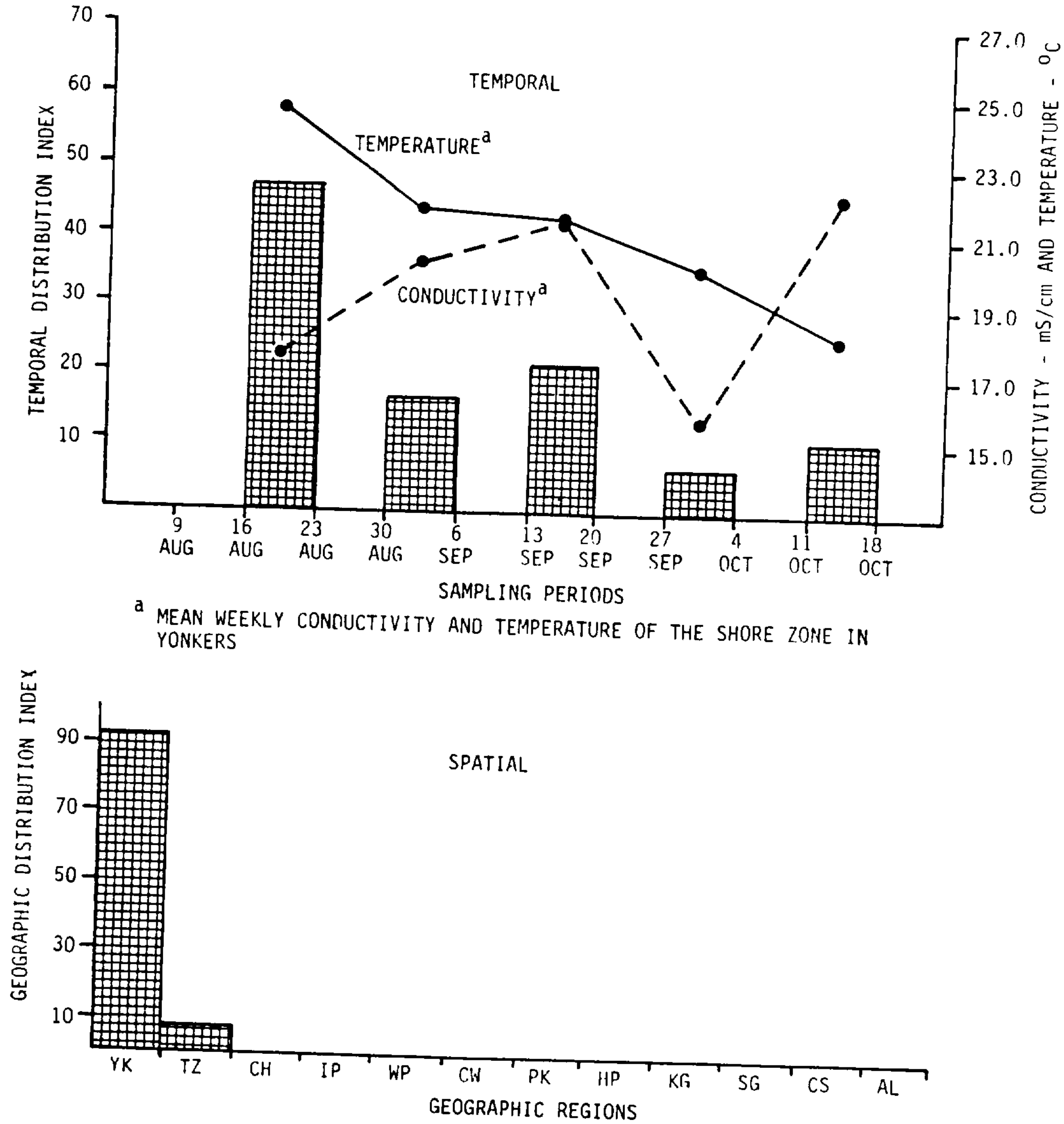


Figure 4.9-2. Patterns in distribution of weakfish young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine sampling).

Avault, 1968) most spawning in the Hudson River estuary probably takes place in the middle and upper segments or in the tributaries.

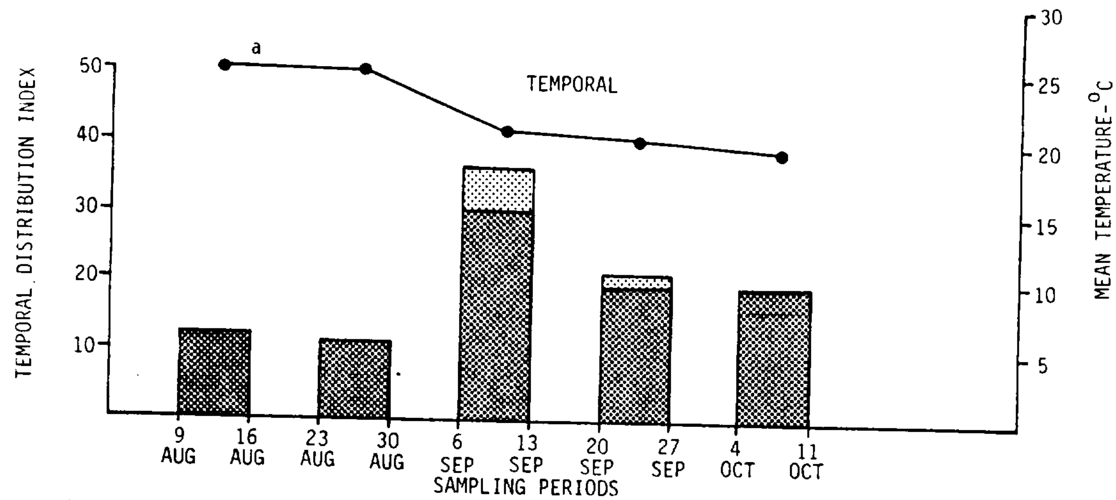
Juvenile catfish are typically found from Poughkeepsie to Albany in the shoal and bottom strata and are most numerous in the Catskill and Albany regions from late July through early August. Yearling and older catfish move into the offshore strata during September and October, and begin a downstream migration in late October to the overwintering grounds when shoal temperatures in the upper estuary drop to 14-15°C. Similar fall movements of white catfish to deeper and warmer waters were reported by Mansueti (1950) and Schmidt (1971).

4.10.1 Young-of-the-Year

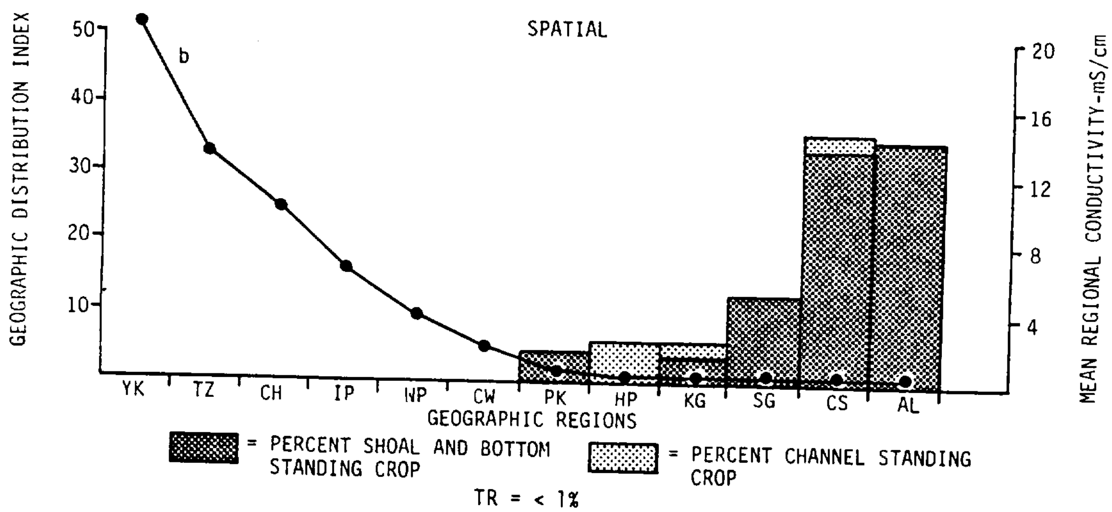
Juvenile white catfish were first detected on the last sampling period of the ichthyoplankton survey (5 July 1982) in the Croton-Haverstraw region (standing crop = 17,388 fish). As in past years, no earlier life stages were detected by the ichthyoplankton sampling program (TI, 1981; Battelle, 1983). Juvenile white catfish were present throughout the Fall Shoals survey in the freshwaters of the Poughkeepsie through Albany regions (Figure 4.10-1). None were collected downstream of the salt front. Highest juvenile abundance during the 1982 August-October Fall Shoals survey occurred during the 6 September sampling period, whereas, a July peak was detected in the 1979 survey and an October peak in the 1980 survey (both the 1979 and 1980 surveys ran from July through December). As expected, most of the standing crop in 1982 was associated with the shoal and bottom strata; only a small proportion of the standing crop occurred in the channel stratum. No juveniles were collected in the shore zone by beach seining.

4.10.2 Yearling and Older Fish

Yearling and older white catfish were collected throughout the Fall Shoals survey. Most fish taken were older than yearling; only a



[a] MEAN TEMPERATURE OF THE OFFSHORE STRATA IN THE POUGHKEEPSIE THROUGH ALBANY REGIONS



[b] MEAN CONDUCTIVITY OF THE OFFSHORE STRATA BY REGION FROM 9 AUGUST THROUGH 11 OCTOBER

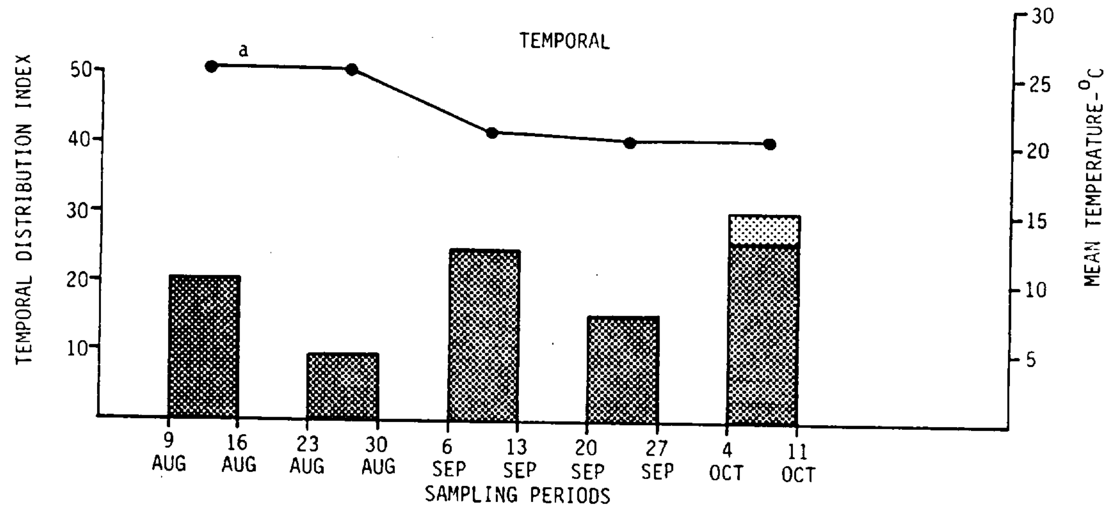
Figure 4.10-1. Patterns in distribution of white catfish young-of-the-year, Hudson River estuary, 1982 (based on Fall Shoals survey).

small proportion of the standing crop was composed of yearlings and these were taken during the last sampling period of the survey (4-11 October) in the Albany region (Figure 4.10-2). Older fish were most abundant in the offshore areas of the upper three regions, particularly Albany (approximately 50% of Fall Shoals standing crop) and in the shore zone of the lower regions, particularly Tappan Zee (approximately 63% of shore zone standing crop). Although these observations are based on a relatively small number of specimens, the same distribution was also described in the 1979 Year Class Report (TI, 1981) and was evident, though somewhat less clear, in the 1980 and 1981 data (Battelle, 1983). No white catfish were encountered during 1979-1982 in the higher salinity waters of Yonkers.

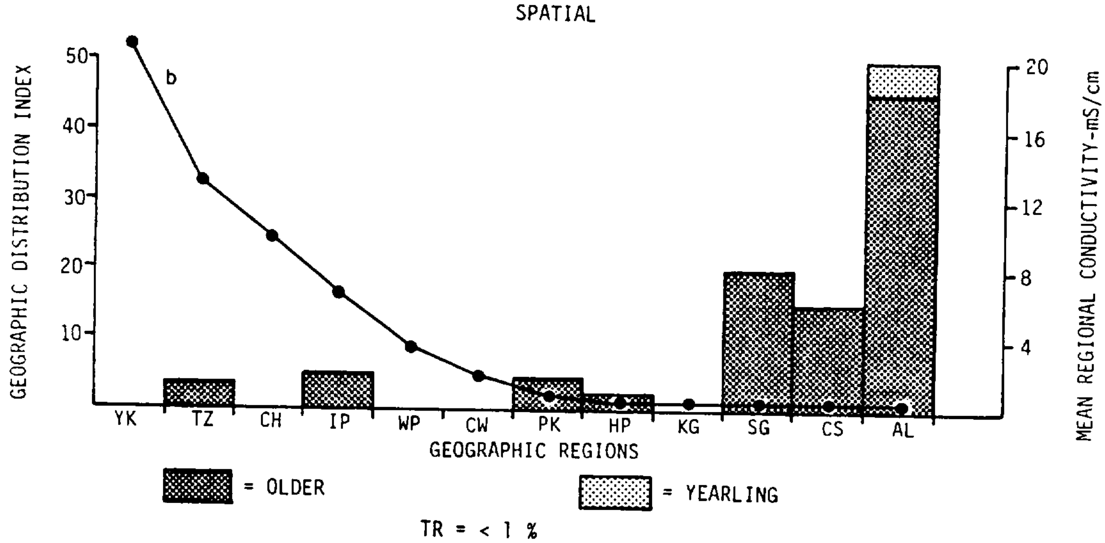
In the shore zone, older fish were most numerous during the first Beach Seine sampling period of 16 August and were taken in relatively low abundances thereafter (Figure 4.10-3). In the offshore area, standing crop generally increased through October suggesting an offshore movement of catfish during this period. In 1979, offshore migration was observed to begin in early September and to peak during October (mean water temperature of 14-15°C) as evidenced by a similar abundance increase in the shoals and a corresponding abundance decline in the shore zone (TI, 1981). These offshore movements were followed later in 1979 by a downstream movement from the upper to the middle and lower estuary (TI, 1981).

4.11 SPOTTAIL SHINER

The spottail shiner, *Notropis hudsonius* (Clinton) occurs in freshwater rivers and lakes in North America from portions of Canada south to Georgia in the east and Iowa and Missouri in the west (Scott and Crossman, 1973). It is a small midwater schooling fish and has a variable diet which includes insects, small crustaceans, water mites, eggs and larvae of their own young and plant material, especially algae. Spottail shiners appear to prefer habitats with sand and gravel bottoms and avoid strong currents (Pflieger, 1975). They are important forage



[a] MEAN TEMPERATURE OF THE OFFSHORE STRATA IN THE POUGHKEEPSIE THROUGH ALBANY REGIONS



[b] MEAN CONDUCTIVITY OF THE OFFSHORE STRATA BY REGION FROM 9 AUGUST THROUGH 11 OCTOBER

Figure 4.10-2. Patterns in distribution of white catfish yearling and older, Hudson River estuary, 1982 (based on Fall Shoals survey).

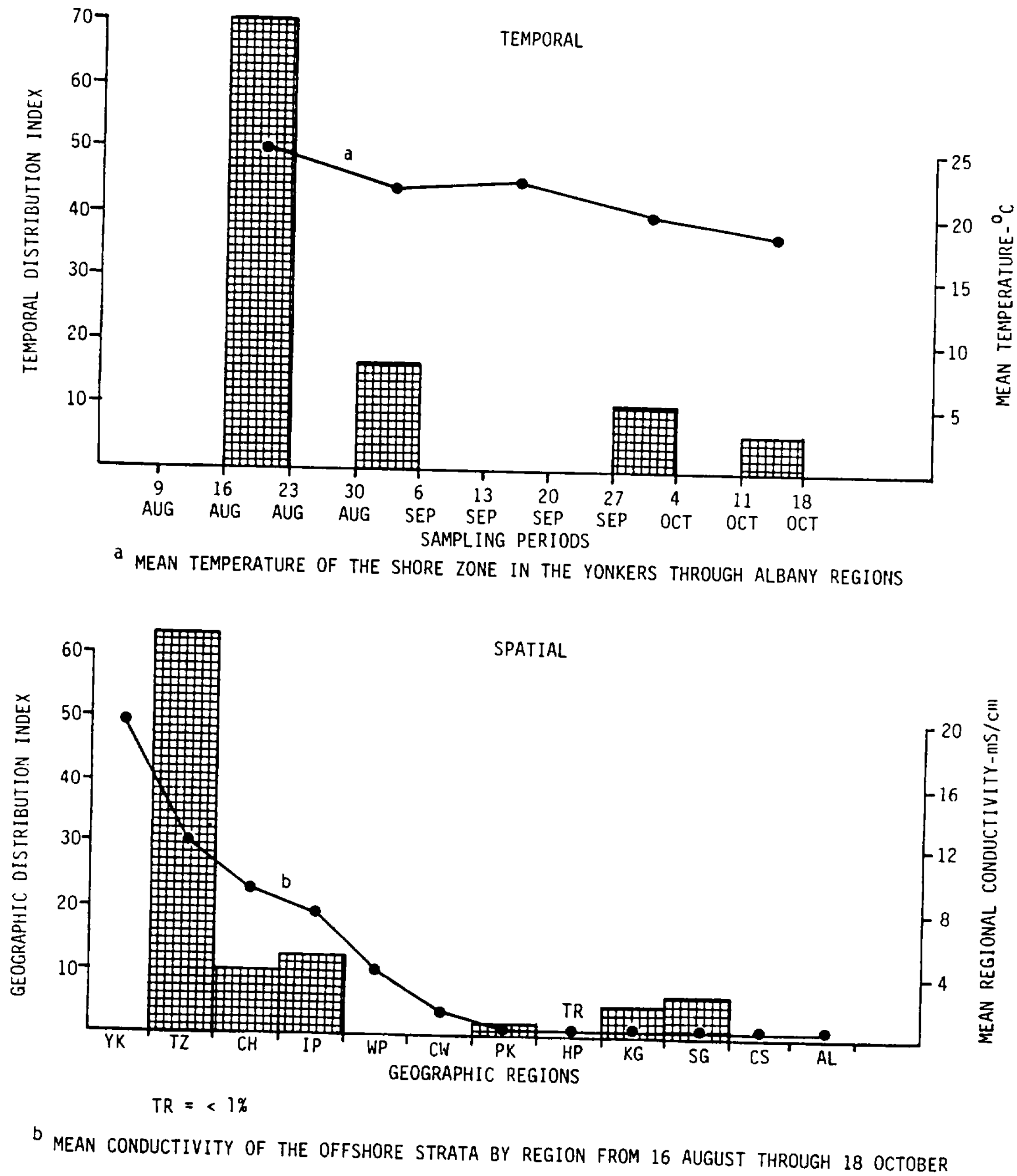


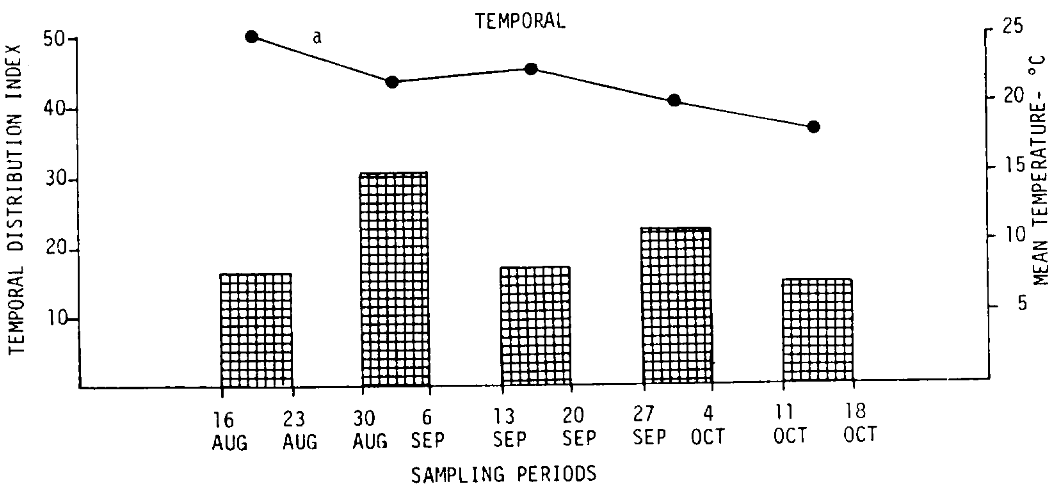
Figure 4.10-3. Patterns in distribution of older white catfish, Hudson River estuary, 1982 (based on Beach Seine survey).

fish throughout their range and very probably in the Hudson River as well. Spawning occurs over sandy shoals during spring and early summer, depending on climate and latitude (Scott and Crossman, 1973).

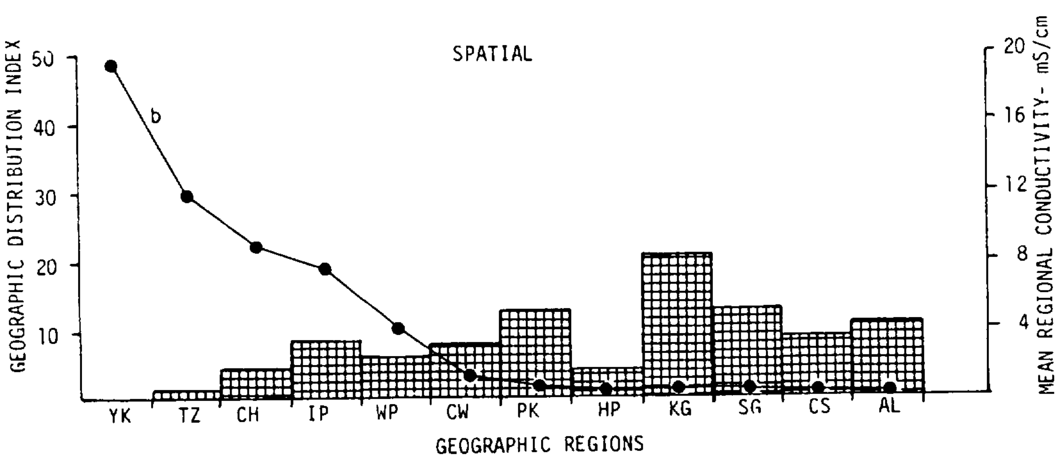
In the Hudson River estuary, spottail shiners overwinter in the bottom and shoal strata of the middle and upper estuary (TI, 1981). During late April, adults move inshore and by May are most abundant in the shore zone of the upper estuary. Concentrations of spottail shiners in this area presumably reflect spawning. Cyprinid eggs and larvae, very likely those of the spottail shiner, have been collected in the Hudson River during late May through mid-August, thus supporting this position (TI, 1981). After spawning is complete in late June, adults disperse throughout the offshore areas. Juveniles remain concentrated in the shore zone through August and then begin to move offshore in September. Peak catches of juveniles in the bottom and shoal strata of the middle and upper estuary have been recorded from late October into winter. Adult abundance increases in the shore zone during early fall; in November, adults move back offshore to their deep-water overwintering areas in the middle and upper estuary.

4.11.1 Young-of-the-Year

Juvenile spottail shiners were concentrated in the shore zone throughout the August through October sampling period (Figure 4.11-1). No juveniles were found in ichthyoplankton collections; in addition, juveniles were absent from all Fall Shoals collections except for those taken during the 23 August sampling period. Juvenile spottail shiners were collected by beach seines from Tappan Zee to Albany with peak numbers in the Kingston region (Figure 4.11-1). This spatial pattern was similar to the distribution of the 1979 juvenile population. Prior to 1979, and in 1980 and 1981, juveniles were concentrated more in the upper estuary. The highest shore zone standing crop of the survey occurred during the first week of September, thereafter, abundances generally declined. In past surveys, juveniles were found concentrated in the shore zone during July and evidence of an offshore movement into



a MEAN TEMPERATURE OF THE SHORE ZONE IN THE YONKERS THROUGH ALBANY REGIONS



TR = < 1%

b MEAN CONDUCTIVITY OF THE SHORE ZONE FROM 16 AUGUST THROUGH 18 OCTOBER

Figure 4.11-1. Patterns in distribution of spottail shiner young-of-the-year, Hudson River estuary, 1982 (based on Beach Seine survey).

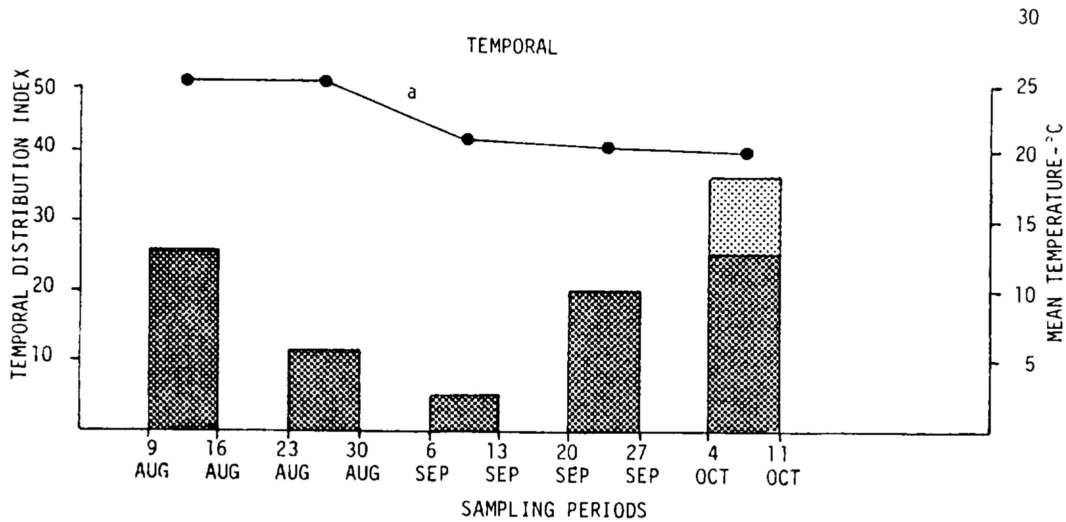
the shoals was observed in September (TI, 1981). Peak offshore movement of juveniles typically occurs from October through mid-December (TI, 1981).

4.11.2 Yearling and Older Fish

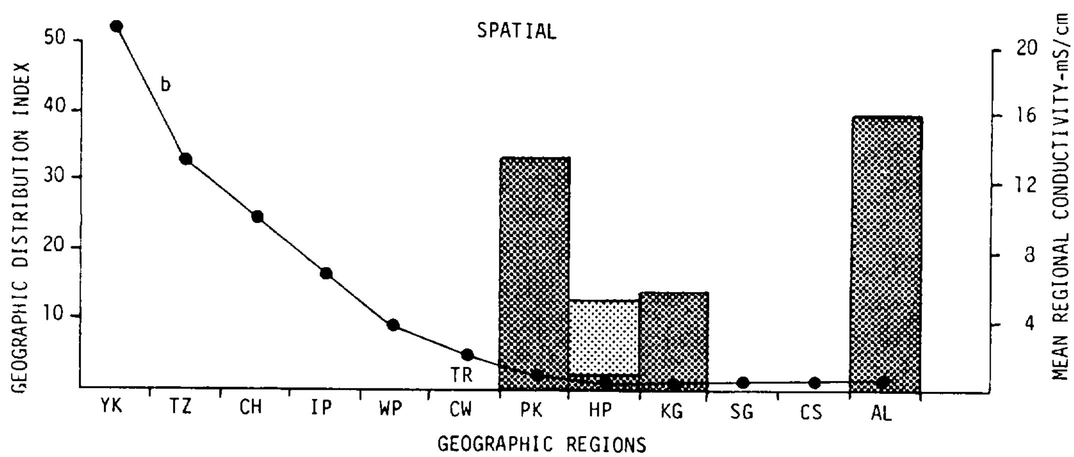
Most of the spottail shiners taken in both surveys were yearlings. Yearlings were collected throughout the Fall Shoals and Beach Seine surveys (Figures 4.11-2 and 4.11-3, respectively). Highest concentrations occurred in the slightly brackish and freshwater environments of the West Point to Albany regions; only trace concentrations were detected below West Point. Standing crop in the shore zone generally increased from the first sampling period in August to the last sampling period in October. In the offshore strata, standing crop declined from the first sampling period in August to minimum levels in early September, and subsequently increased to highest levels of the survey in October coincident with the shore zone peak. Increases in standing crop in both the shore zone and offshore strata during late September and October may reflect a movement of spottail shiners from the tributaries into the mainstem of the estuary on their way to overwintering grounds. Spottail shiners apparently overwinter in the offshore area of the middle and upper estuary and major offshore movements from the shore zone to the bottom and shoal strata have been reported to occur in November (TI, 1981).

4.12 ATLANTIC STURGEON

The Atlantic sturgeon, *Acipenser oxyrhynchus* (Mitchill) is a member of the family Acipenseridae. It is an anadromous species, spending the majority of its life in coastal waters, ascending estuaries only to spawn. Adult Atlantic sturgeon range from Labrador and the Gulf of St. Lawrence to eastern Florida. In the Hudson River estuary Atlantic sturgeon may be found from Croton-Haverstraw (RM 34) north to Catskill (RM 124). Although Atlantic sturgeon are collected only



[a] MEAN TEMPERATURE OF THE OFFSHORE STRATA IN THE POUGHKEEPSIE THROUGH ALBANY REGIONS



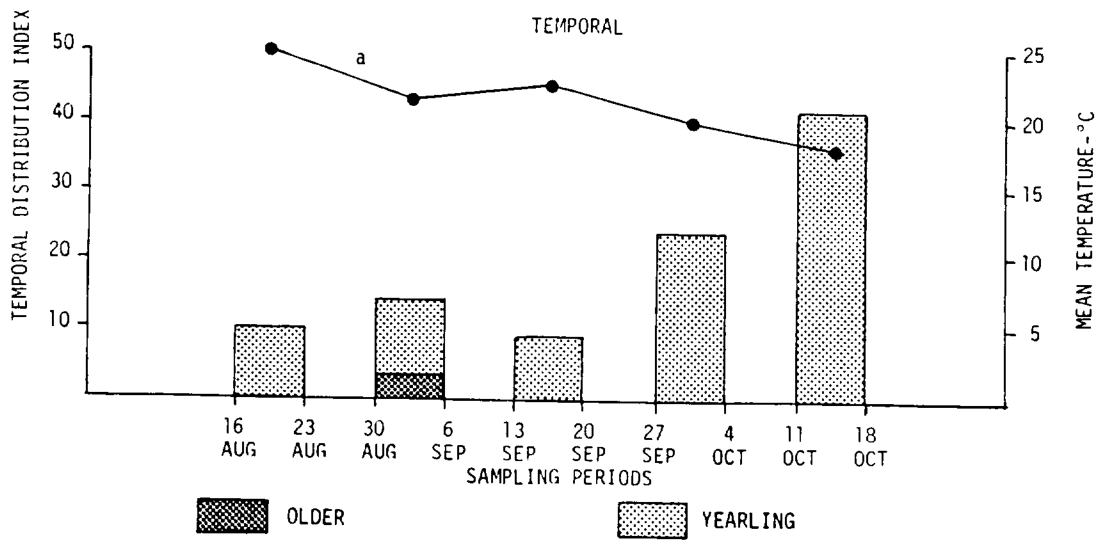
[b] MEAN CONDUCTIVITY OF THE OFFSHORE STRATA FROM 9 AUGUST THROUGH 11 OCTOBER

PERCENT SHOAL AND BOTTOM STANDING CROP

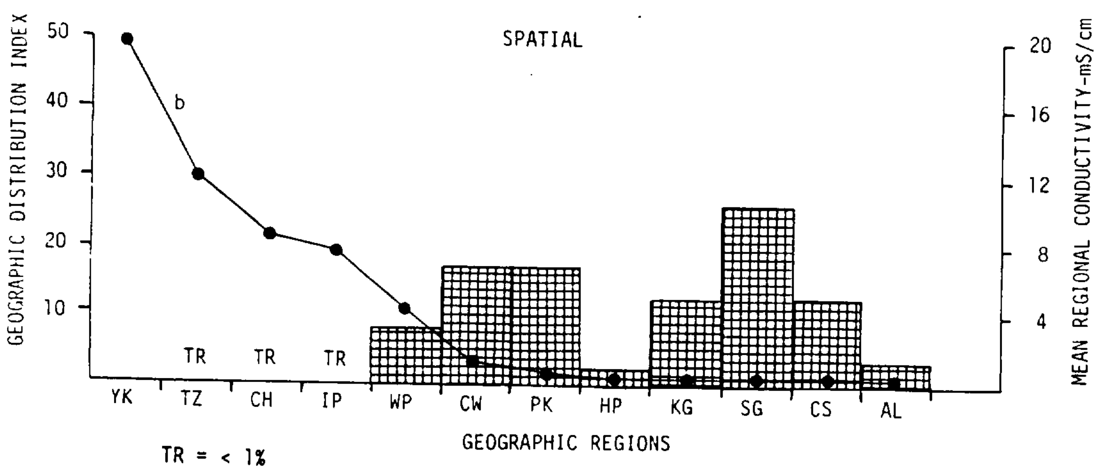
PERCENT CHANNEL STANDING CROP

TR = < 1%

Figure 4.11-2. Patterns in distribution of spottail shiner yearling, Hudson River estuary, 1982 (based on Fall Shoals survey).



[a] MEAN TEMPERATURE OF THE SHORE ZONE IN THE YONKERS THROUGH ALBANY REGIONS



[b] MEAN CONDUCTIVITY OF THE SHORE ZONE BY REGION FROM 16 AUGUST THROUGH 18 OCTOBER

Figure 4.11-3. Patterns in distribution of spottail shiner yearling, Hudson River estuary, 1982 (based on Beach Seine survey).

incidentally, they are more abundant than the shortnose sturgeon (TI, 1981).

The adults are closely associated with their natal estuarine system, but they will occasionally be collected offshore (Murawski and Pacheco, 1977). In the spring, adults begin to move towards freshwater to spawn. Spawning occurs over hard bottoms in shoal areas when water temperatures are 13-18°C (Jones *et al.*, 1978). Spawning appears to occur only once during the season (Scott and Crossman, 1973), with individual sturgeon possibly requiring a 3-6 year resting stage prior to another spawn. Males reach sexual maturity by Age XXII and females by Age XXVIII. Fecundity estimates are 500,000 to several million eggs per female (TI, 1981). Soon after spawning, adults move out of the estuary and back to the ocean.

The demersal, adhesive eggs are 2-3 mm in diameter and hatch in 4-7 days at temperatures of 18-20°C (Jones *et al.*, 1978). Upon hatching, larvae are 11 mm TL and absorb the yolk-sac in 6 days. Older larval stages of *A. oxychynchus* are undescribed.

Juveniles usually remain within the estuary for up to six years at which time they have reached 760-915 mm in length. While still in the estuary, juveniles are demersal consuming chironomid larvae, small crustaceans, and plant material (TI, 1981). After emigration from the estuary, juveniles occasionally make oceanic excursions of up to 1450 km (Magnin and Beaulieu, 1963). The Atlantic sturgeon is slow growing reaching a length of 1650-1900 mm and a weight of 68 kg.

4.12.1 Juveniles

No juvenile Atlantic sturgeon were collected in the Hudson River estuary in 1982.

4.12.2 Yearling and Older Fish

A total of four adult Atlantic sturgeon were taken during the Fall Shoals program. Three were taken on 6 September and one was taken on 6 October. These specimens were taken in Tappan Zee (RM 33), West Point (RM 53 and 54), and Hyde Park (RM 80) regions, and were probably emigrating out of the estuary after the spawning season and as water temperatures declined.

4.13 SHORTNOSE STURGEON

The shortnose sturgeon, *Acipenser brevirostrum*, a member of the family Acipenseridae, is an rare and endangered species (Dadswell, 1979). The shortnose sturgeon occurs along the eastern Atlantic coast, from the St. John River in New Brunswick south to the St. Johns River in Florida (Vladykov and Greeley, 1963). At one time the shortnose sturgeon was an abundant species in tidal waters from Connecticut to the Potomac River (Scott and Crossman, 1973). This species is most often seen in large tidal rivers, but may also occur in the inshore marine waters. A landlocked population is present in the Connecticut River (Taubert, 1980).

The shortnose sturgeon is a slow growing species, with a maximum size of 1357 mm TL and 16.5 kg (Jones *et al.*, 1978), but probably only reaches about 885 mm TL and 4.1 kg in the Hudson River (Scott and Crossman, 1973). Lifespan is at least 14 years in the Hudson River, and as long as 27 years in the Saint John River, N.B. (Scott and Crossman, 1973). Sexual maturity is reached at approximately 500 mm TL for males and 600 mm TL for females (Scott and Crossman, 1973), with first spawning occurring at about 8-17 years of age (Jones *et al.*, 1978; Taubert, 1980). Shortnose sturgeon only spawn once or twice in their lifetime, with the second spawning occurring at 14-20 years of age (Taubert, 1980).

In the Hudson River, immature shortnose sturgeon and adults in resting condition (which will not spawn the next spring) overwinter in the upper reaches of the lower estuary, while those approaching spawning condition overwinter in the lower part of the upper estuary (TI, 1981). The latter move upriver in spring as water temperatures rise above $5^{\circ}C$, and spawn in late April and early May in the uppermost part of the estuary, when temperatures range from 6 to $17^{\circ}C$ (TI, 1981). Females produce between 48,000 and 99,000 eggs (Jones *et al.*, 1978)

Mature ovarian eggs average 3.0 mm in diameter. The eggs are demersal and strongly adhesive at first, becoming essentially nonadhesive after 2 hr. They are half brown and half greyish white and hatch in 4-13 days (Jones *et al.*, 1978). Larvae are about 8-10 mm at hatching and are heavily pigmented (Taubert and Dadswell, 1980). The yolk is nearly absorbed at 13-15 mm TL at approximately two weeks of age (Taubert and Dadswell, 1980). Larvae remain on the bottom for several days after hatching (Jones *et al.*, 1978). Relatively few sturgeon larvae or YOY have been collected in the Hudson River (TI, 1981), and since shortnose sturgeon larvae have only recently been described (Taubert and Dadswell, 1980; Bath *et al.*, 1981) little is known about how their abundance and distribution in the Hudson compares with that of the Atlantic sturgeon.

4.13.1 Juveniles

None were taken during the 1982 sampling period.

4.13.2 Yearling and Older Fish

Only one adult fish was collected during the entire sampling period on the Hudson River in 1982. This individual was taken on the bottom with the epibenthic sled on 6 October at 0217 in the Hyde Park region (RM 81) during the Fall Shoals sampling survey. Due to only the one individual, geographic and temporal distribution trends cannot be discussed.

5.0 GROWTH AND MORTALITY

Estimates of growth and mortality during the larval and early juvenile stages are presented in this section for five species: striped bass, white perch, American shad, Atlantic tomcod, and bay anchovy.

In previous year class reports, growth estimates were presented for striped bass and white perch during the late larval through early juvenile period, based on length data collected mainly in July (TI, 1981). For 1982, corresponding estimates could not be calculated the same way as in previous years because sampling was not conducted during that period. To compensate for the missing data, growth for that interval was inferred by extrapolating backward the mean length data from August-October, and extrapolating forward the mean length data from late June-early July. In doing this, certain assumptions were made about recruitment, gear avoidance, and the shape of the growth curve. This approach and its underlying rationale are described in Section 5.1.1.1 using the striped bass data as an example. An independant estimate of growth based on maximum length data is also presented, in order to corroborate the results based on mean length. Growth estimates for white perch and American shad (Sections 5.2.1.1 and 5.3.1.1) were calculated by the same method.

Mortality was calculated for previous year class reports by two methods (TI, 1981). Late larval and early juvenile mortality of striped bass was calculated by the method of Sette (1943), which is based on lengthfrequency data. Mortality of late larval/early juvenile white perch and mortality of larger young-of-the-year for both striped bass and white perch was estimated by the population decline method based on standing crop data (Section 2.2.3.3). In 1982, because no ichthyoplankton samples were collected after the week of 5 July, sufficient data were not available for using the length-frequency method (this point is further discussed in Section 5.1.2.1). Therefore, all 1982 mortality estimates were calculated by the population decline method.

5.1 STRIPED BASS

5.1.1 Growth

5.1.1.1 Larvae and Early Young-of-the-Year

Growth of larval and early juvenile striped bass was examined in previous years in two ways: (1) observation of changes in mean lengths and length-frequency distributions from week to week, and (2) estimation of average growth rate during the intervals from hatching to 30 mm and from 30 mm to 60 mm (TI, 1981). Growth rates calculated by this method ranged from 0.49 to 0.84 mm per day up to 30 mm and from 0.87 to 1.10 mm per day between 30 and 60 mm during the years 1973-1979 (TI, 1981). The method was reviewed in the 1980-81 Year Class Report (Battelle, 1983), but no data or growth estimates were presented for those two years. In 1982, a four-week gap (12 July-8 August) occurred between ichthyoplankton sampling and juvenile sampling. This was during the period of early summer rapid growth when the mean length increased roughly from 10 to 60 mm. Although this prevents a direct comparison with previous years' growth estimates, it is still possible to make some relevant observations from the 1982 data.

Mean length in 1982 estimated from ichthyoplankton samples followed the same pattern from week to week as in previous years: the mean length increased negligibly for a period of several weeks (eight in 1982), through most of May and all of June, and then started to increase in July (Table 5.1-1). This apparent lack of growth during the eight-week period is due to two factors: (1) around the time of yolk-sac absorption at 5.5-6.0 mm, striped bass larvae reach a growth plateau which was observed in laboratory-reared individuals to last 1-3 weeks (Rogers *et al.*, 1977), and (2) while the numbers of older larvae are rapidly diminished by high mortality rates, recently hatched larvae continue to be recruited. Recruitment in 1982 was largely completed by the week of 21 June, when 15% of the standing crop was comprised of eggs or small (<5 mm TL) larvae; in subsequent weeks, the proportion of new recruits was only about 1-2% (Table 5.1-2). Although the mean length of

TABLE 5.1-1. MEAN LENGTHS (mm TL) OF STRIPED BASS ESTIMATED FROM ICHTHYOPLANKTON SAMPLES, HUDSON RIVER ESTUARY, 1982.

10-16 May	4.6	14-20 Jun	6.0
17-23 May	5.5	21-27 Jun	6.2
24-30 May	5.5	28 Jun-4 Jul	6.9
31 May-6 Jun	6.2	5-11 Jul	10.6
7-13 Jun	6.5		

the population did not increase much until July, substantial growth was occurring during May and June: those larvae which had hatched early in the season had grown to nearly 20 mm by the week of 21 June.

TABLE 5.1-2. EGGS AND RECENTLY HATCHED LARVAE (<5 mm TL) AS A PERCENTAGE OF STRIPED BASS ICHTHYOPLANKTON STANDING CROP, HUDSON RIVER ESTUARY, 1982.

10-16 May	87%	14-20 Jun	20%
17-23 May	56%	21-27 Jun	15%
24-30 May	30%	28 Jun-4 Jul	2%
31 May-6 Jun	8%	5-11 Jul	1%
7-13 Jun	3%		

After yolk-sac absorption, larvae begin a phase of rapid growth in which length increases exponentially at least until transformation to the juvenile stage at around 16 mm TL (Rogers *et al.*, 1977). Mean length of striped bass in the Hudson River continues to increase exponentially throughout much of July, to around 50-60 mm, and then growth rate decreases through the remainder of the year (TI, 1981). To compare growth in 1982 with growth in previous years, estimates were needed of the dates when the population mean reached 30 and 60 mm. Since these could not be generated by linear regression of mean length data between those two sizes as they had been in previous years because of the missing data, they were estimated by extrapolating from the available data.

The date when 60 mm mean length was reached was estimated by extrapolating back the mean lengths from the Beach Seine survey. Fall Shoals (epibenthic sled and Tucker trawl) data were excluded because (1) these data were less representative of the population than Beach Seine data, since most of the fish were in the shore zone during these fall juvenile surveys (70-99%, based on combined standing crop, Appendix B, Table B-7), and (2) Fall Shoals data had considerably higher variability, both among weeks and (as shown by larger standard errors) within weeks. A logarithmic growth curve (Equation 15, Appendix A) was used because the growth rate was decreasing during this period. The resulting equation fitted the data very well (curve A, $r^2 = 0.99$, Figure 5.1-1) and also closely resembled the eye-fitted curve used to describe growth in previous years (TI, 1981). It produced the estimate that the mean length reached 60 mm on 10 August (Equation 16, Appendix A). This agreed fairly well with estimates for previous years, which ranged from 30 July to 12 August, with the average being 5 August (TI, 1981).

A second point for establishing the growth curve was then selected from the ichthyoplankton data. The point selected was the week of 21 June when the mean length was 6.2 mm. Selection criteria were (1) that the proportion of larvae under 5 mm in every week afterwards was <5%, and (2) the maximum size attained by the older fish was <20 mm. The rationale behind those criteria was that (1) earlier weeks would give a biased estimate of the population mean because they exclude later cohorts not yet recruited, and (2) earlier cohorts are probably undersampled in later weeks because they have grown to a size capable of significant gear avoidance.

From these two points, 60 mm on 10 August (from the logarithmic equation) and 6.2 mm on 24 June (midpoint of the sampling week when recruitment was approximately complete), based on the assumption stated above that growth is exponential from roughly 6 to 60 mm, an exponential growth curve was calculated (Equation 17, Appendix A). This exponential relationship (curve B, Figure 5.1-1) provided an estimate of 26 July as

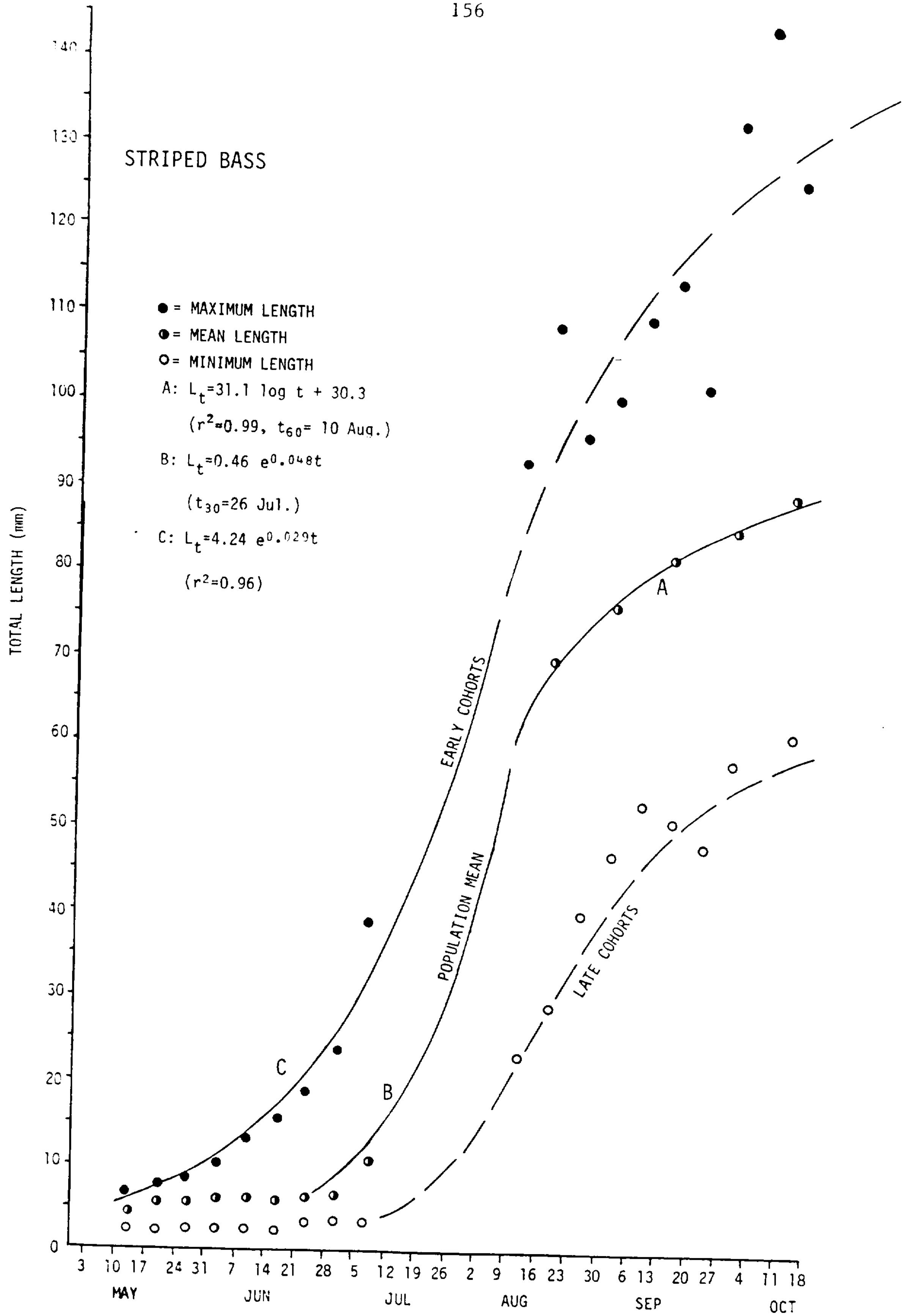


Figure 5.1-1. Growth of striped bass larvae and early juveniles (mm TL) estimated from ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982. Solid lines are exponential and logarithmic curves for by linear regression; see text for explanation. Dashed lines were drawn by eye.

the date when 30 mm was reached (Equation 18, Appendix A), and an average growth rate between 30 and 60 mm of 2.1 mm per day (Equation 19, Appendix A). If hatching is assumed to have occurred at 4 mm on 27 May, the midpoint of the week with peak egg abundance, then the average growth from hatching to 30 mm was 0.4 mm per day (Equation 19, Appendix A).

Time of hatching can also be estimated by extrapolating growth backwards. Exponential growth begins at about 7 mm. This was estimated by fitting a curve by eye to the data from three replicates at 18^{o}C presented by Rogers *et al.* (1977), and then plotting that curve on a logarithmic scale. Above 7 mm the plot was a straight line, indicating an exponential relationship. Mean length of Hudson River striped bass larvae in 1982 reached 7 mm on about 27 June (curve B, Figure 5.1-1). Larvae reach 7 mm about 23 days after hatching (Rogers *et al.*, 1977), so the average hatching date was about 4 June, and growth averaged 0.5 mm per day up to 30 mm. This agrees fairly well with the hatching date and growth rate inferred from the peak in egg abundance.

Because of the limited data available for estimating the 1982 growth rates, a second estimate of late larval and early juvenile growth was made for the purpose of comparison, using maximum lengths rather than mean lengths. The largest size attained by the fish in any particular week most likely represents individuals from the earliest cohorts of the year class to hatch. The increase in maximum length from week to week thus approximates the growth pattern of individual fish (the fastest growing ones) from those early cohorts. In some fish populations, growth of early cohorts can be enhanced by utilization of a particular food resource which is not available to later cohorts, resulting in sufficient disparity in growth rates within a year class to cause a bimodal distribution of lengths (Timmons *et al.*, 1980). This does not appear to occur in Hudson River striped bass populations, because length-frequency distributions remain unimodal throughout the first several months of growth (TI, 1981).

Maximum length values, unlike the mean length data, are not biased (lowered) by additional recruitment over time. Also, gear avoidance does not introduce a serious bias, as long as at least a few of the large fish are caught. To verify this assumption, log-transformed maximum lengths from the ichthyoplankton sampling periods were plotted against time (sampling week). The data approximated a straight line, due to exponential growth, and the points late in the sampling season did not fall below the line (they would if they seriously underestimated the true maximum length for the population). This lack of bias in maximum length data in contrast to mean length data is due to the fact that the proportion of large fish in the samples, which may substantially underestimate the true proportion, does not affect the maximum length value, whereas it does affect the estimate of the mean. Since neither recruitment nor gear avoidance biases the maximum length data, all of the ichthyoplankton sampling periods can be used to estimate growth of early cohorts. This made it unnecessary to include Beach Seine or Fall Shoals data to provide a sufficient number of data points to establish the exponential growth curve, so a logarithmic curve was not calculated from maximum lengths. An exponential curve was estimated directly from the nine weekly values of maximum length from the ichthyoplankton sampling, using Equation 17 (Appendix A).

The resulting equation (curve C, Figure 5.1-1) fitted the data well ($r^2 = 0.96$). A test of whether extending this curve beyond the end of ichthyoplankton sampling is representative of actual growth is to determine how well it predicts size when juvenile sampling began in August. If it is assumed that as in past years the growth rate did not begin to decrease (marking the end of exponential growth) much before early August, then the extrapolation of the exponential curve through July into August should come close to the maximum observed length for the week of 9 August, which it does. The dates when 30 and 60 mm were reached, estimated from the maximum length curve using Equation 18 (Appendix A), were 7 July and 30 July, respectively (Figure 5.1-1). This represents an average growth rate from 30 to 60 mm of 1.3 mm per day, 38% lower than the estimate derived from mean lengths. The growth exhibited by the earlier cohorts occurred about 1-1/2 to 3 weeks earlier, when temperatures were lower, so it is not surprising that the growth rate is lower.

To estimate growth from hatching to 30 mm for the early cohorts, an estimate of hatching date is needed. At 15°C, laboratory-reared striped bass larvae took approximately 25-35 days to reach 7 mm (Rogers *et al.*, 1977:92-94). Since the early cohorts in 1982 reached 7 mm around 18 May (curve C, Figure 5.1-1), this means they would have hatched on about 18 April, averaging 0.3 mm growth per day up to 30 mm. Data from field collections, however, indicate that the earliest that striped bass hatch in significant numbers in the Hudson River is the first or second week in May (TI, 1981). This difference may be due to the difference between laboratory and field conditions. In 1982, sampling was not conducted before the week of 10 May. The numbers of eggs and yolk-sac larvae present during that week suggest that hatching in 1982 probably began around the first week in May. If 6 May is used as the estimate of early hatching in 1982 (one week prior to the mid-date of the first sampling week), then growth up to a size of 30 mm averaged 0.4 mm per day, the same as the estimate produced from mean length data.

The two estimates of growth in 1982, based on mean lengths and maximum lengths, agreed reasonably well with each other. Compared to previous years' growth estimates, however, the 1982 estimates indicated slower growth under 30 mm, faster growth between 30 and 60 mm, and about the same overall growth rate from hatching to 60 mm. The difference lies in the estimation of when the population mean reached 30 mm. This date was estimated from Beach Seine and Fall Shoals data in the 30 to 60 mm size range in previous years. Although 30 mm fish may be fully recruited to the sampling gear, there is a substantial proportion of the population in July which has not yet reached that size. Maximum lengths in 1982 indicate that the oldest (or fastest growing) fish reached 30 mm in early July, and minimum lengths showed that others had not reached that size until the second half of August. In other words, recruitment to the gear is not complete when the mean length observed by that gear reaches 30 mm (it can hardly be much less, because if smaller fish are present they are seldom retained by the mesh), but rather when all (or most) individuals of the population have reached 30 mm. Therefore, mean lengths derived from fall juvenile sampling in July overestimate the true population mean length by an amount which decreases during the month, as a larger percentage of the population are recruited to the gear. This results in underestimating the growth rate during that period. Another indication that the growth from 30 to 60 mm during 1973-1979 was underestimated is that if the reported growth rates are extrapolated back, assuming exponential growth, then the population mean would have been 6 mm between 8 April and 7 May (average of 22 April). This is clearly too early in the year for an early post yolk-sac larva of a mid-season cohort when yolk-sac larvae usually peak in late May or early June.

In conclusion, analysis of the 1982 data indicates that striped bass growth between hatching and 30 mm is slower, and growth between 30 and 60 mm is faster, than estimated by the method of previous year class reports. No direct comparison is available for comparing 1982 growth with estimates made in previous years, but the overall growth rate from hatching to 60 mm was was similar to the 1973-1979 period. In order to verify estimates of growth rate during the larval and early juvenile stages, age determination by otoliths could be utilized. This would make possible an evaluation of how closely growth inferred from increasing lengths observed in a population as a whole reflects the actual growth of individuals (Laroche *et al.*, 1982).

5.1.1.2 Young-of-the-Year

Juvenile striped bass growth data for 1982 are available from mid-August to mid-October (Figure 5.1-2). Fish collected in the shore zone, which represent the bulk of the population in the summer, grew from 70 mm mean length to 89 mm mean length in an eight-week period (week of 16 August to week of 11 October), an average growth of 0.3 mm per day. The growth rate decreased somewhat during this period, indicating that the fish were no longer in the exponential phase of growth, which for July in previous years, was estimated at 0.9 to 1.1 mm per day (TI, 1981), and probably was even higher (Section 5.1.1.1).

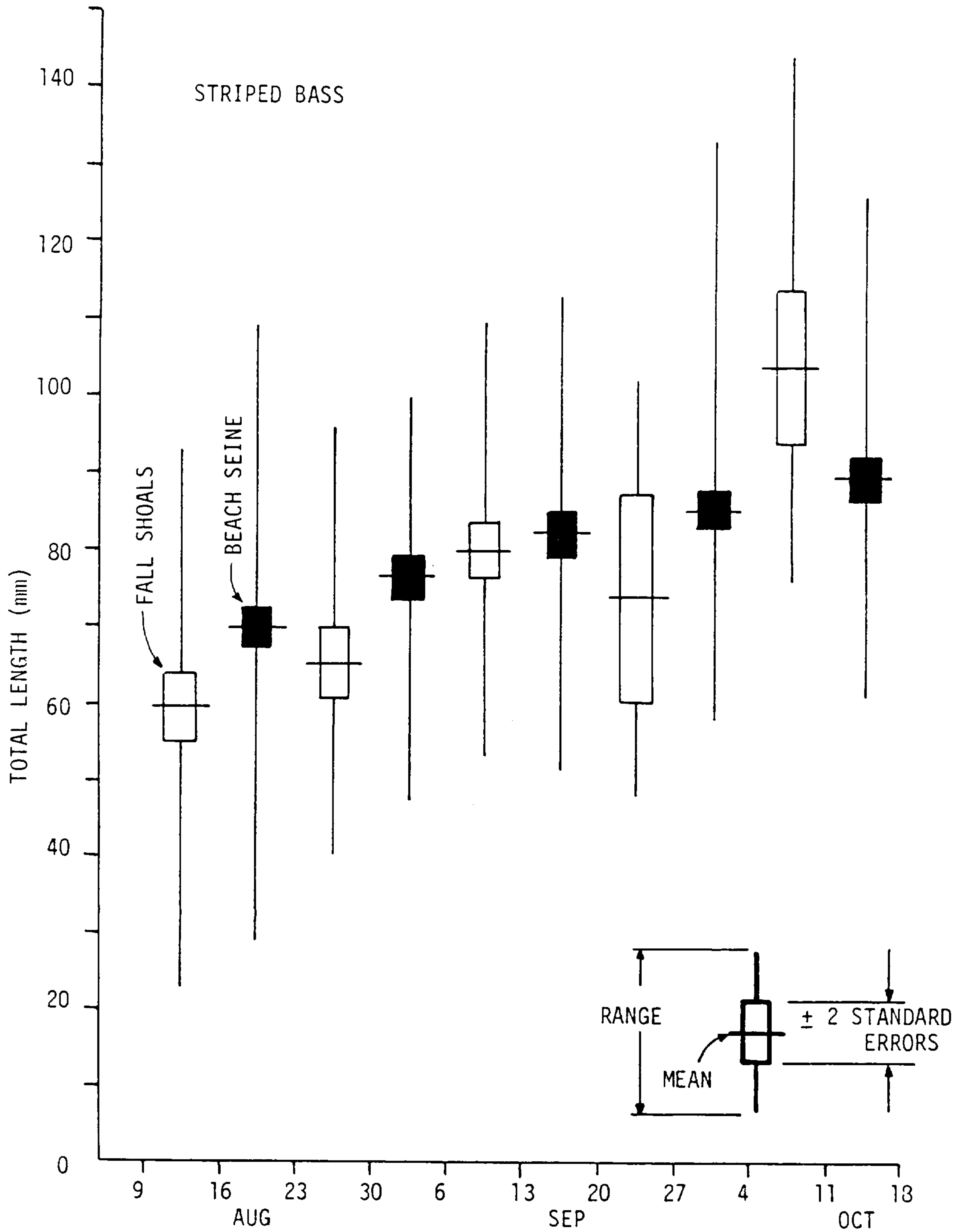


Figure 5.1-2. Growth of striped bass juveniles (mm TL) estimated from Fall Shoals and Beach Seine surveys, Hudson River estuary, 1982.

During August, the average sized striped bass juveniles which were collected in Fall Shoals samples were generally smaller than those in the shore zone. This may indicate that the faster growing (or older) individuals move into shallow water sooner or that fish which have moved into shallow areas grow faster. The trend was reversed in October, which may reflect that the larger fish are the earliest ones to enter deeper water as they begin migrating down the estuary. This pattern is consistent with observations in 1979, when the difference between Fall Shoals and Beach Seine mean lengths increased in November and December (TI, 1981). There were no substantial size differences among river regions.

5.1.2 Mortality

5.1.2.1 Larvae and Early Young-of-the-Year

Mortality of striped bass from 6 to 20 mm in 1982 could not be calculated by the length-frequency method previously used, because ichthyoplankton sampling ended with the week of 5 July, when there were still small larvae present (<5 mm). The length-frequency method requires sampling until all larvae have grown larger than the maximum size under consideration (20 mm in this case) because it uses an estimate of the total number of fish which survive to each size interval during the entire year. If sampling ends before the maximum size is reached, as it did in 1982, then the total number of larvae that reach a certain size (e.g., 15-16 mm) during that year is underestimated. This is because those individuals that were smaller than that when sampling ended are not sampled when they eventually reach that size. The extent to which any particular size class is underestimated increases with increasing size. For example, only a small percentage of the larvae hatched in 1982 had not yet reached 7 mm by the end of sampling, so the 6-7 mm size interval would only be slightly underestimated. In contrast, probably less than half of the striped bass that would survive to 20 mm in 1982 had reached that size by the end of sampling, based on the observation that the mean length for the population did not reach 20 mm until after sampling ended (Figure 5.1-1). A mortality estimate based on the length-frequency method in 1982 would therefore substantially overestimate actual mortality because of not accounting for many of the fish which would survive to the larger size intervals. Mortality was estimated instead by the population decline method.

Mortality of striped bass from the week of peak standing crop (week of 31 May) through the last week of ichthyoplankton sampling, calculated by the population decline method (Equations 20 and 21, Appendix A), was 9% per day. Spawning continued through the week of 21 June, when eggs and yolk-sac larvae under 5 mm comprised 15% of the standing crop, and for at least two additional weeks in small amounts (Appendix B, Tables B-1 through B-4; Appendix D, Table D-1). This means that recruitment of striped bass to the ichthyoplankton was not complete until about the seventh week of sampling (or even later if the smaller yolk-sac larvae are not fully recruited to the 505-μm mesh), even though a peak in standing crop was observed during the fourth week. Therefore, standing crop is an underestimate of the actual population from the observed peak until recruitment was completed, causing mortality to be underestimated by this method.

The pattern of weekly standing crops in 1982 indicated a secondary peak near the end of the spawning season during the week of 28 June (Figure 5.1-3). Mortality remained relatively high for at least one week into July. Because of the wide range in ages present during any one week, it is not possible to discern from standing crop data whether the mortality rate of the 1982 year class decreased at approximately 10 mm as noted for three of four previous years examined by the length-frequency method (TI, 1981).

5.1.2.2 Young-of-the-Year

Mortality of striped bass juveniles over 30 mm in length was estimated in previous years by using the weekly combined standing crop data from the Fall Shoals and Beach Seine surveys as a measure of

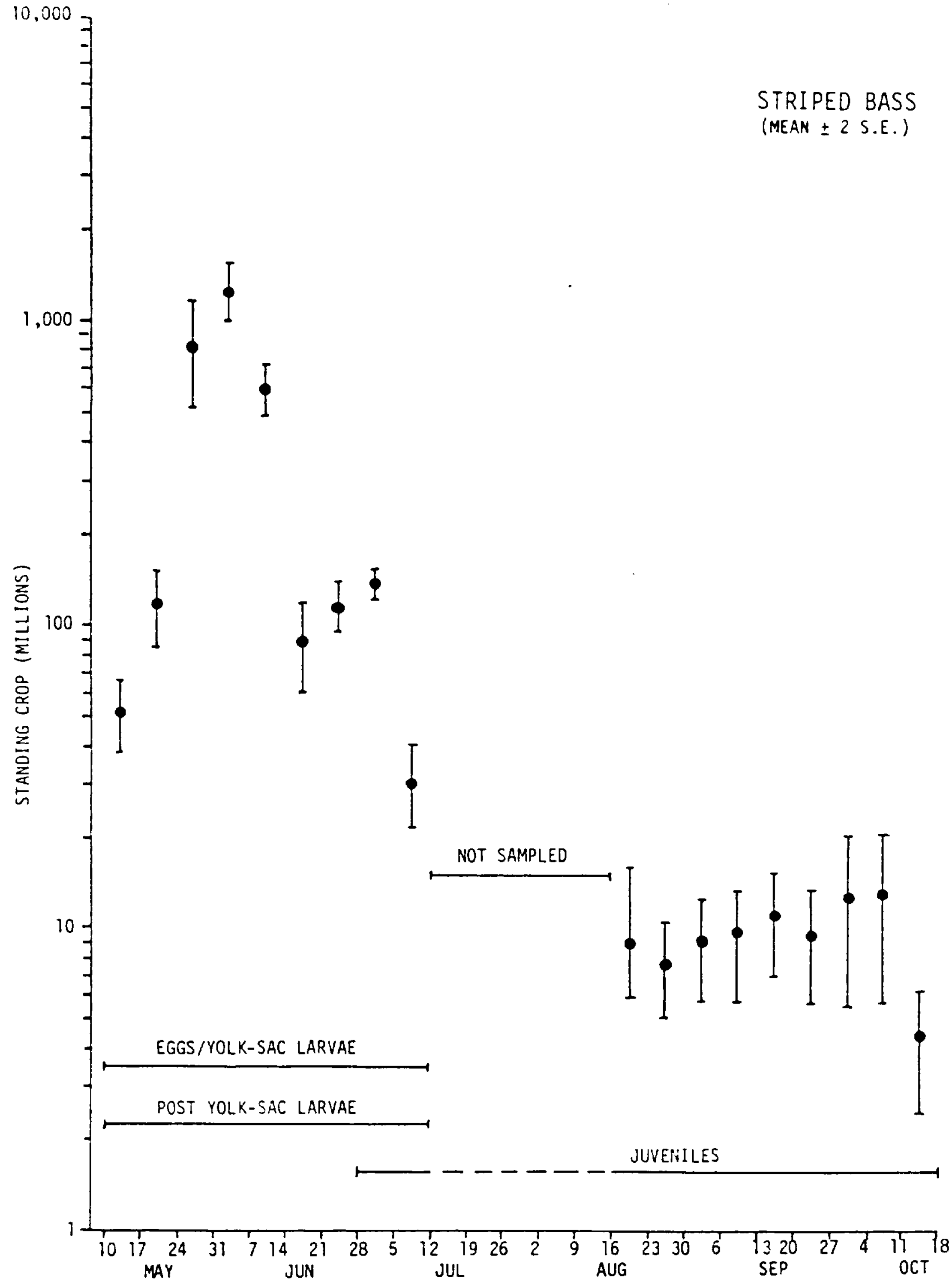


Figure 5.1-3. Standing crop of striped bass early life stages, based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982.

population decline. Estimates for 1975-1979 ranged from 0.3 to 1.8% per day (TI, 1981). During 1976-1981 the typical pattern of the standing crop survival curve was (1) a period of moderate mortality around July and August (less than in the larval and early juvenile stages) followed by (2) a period of reduced mortality rate during September and sometimes the latter part of August, and then (3) reduced standing crops in the fall attributed to dispersal from the sampling area in addition to mortality (TI, 1979, 1980a, 1980b, 1981; Battelle, 1983). In 1982 juvenile sampling did not begin until after the population had reached the phase of reduced mortality. During the nine weeks from mid-August to mid-October when estimates are available for both the shore zone and the rest of the river, there was no appreciable change in the size of the population, which had stabilized around 10 million (Figure 5.1-3). The mortality rate for the period of moderate mortality cannot be estimated by the linear regression method previously used because of the lack of samples during that period. An approximation of the average mortality rate from early July to mid-August can be made from the standing crop estimates for the last week of ichthyoplankton sampling and the first full week of juvenile sampling. Based on a standing crop reduction from 30.9 million to 8.8 million over a six-week period, the mortality was about 2.9% per day (Equation 20, Appendix A, with $N_o=30.9x10^6$, $N_t=8.8x10^6$, t=42 days; and Equation 21, Appendix A). This can only be considered approximate because only two data points were used, and those were from different sampling gears. The mortality represented by this estimate includes some which occurred during the post yolk-sac stage, since much of the population had not yet reached the juvenile stage in early July. This mortality estimate may be somewhat low because by early July the older fish of the year class were large enough for gear avoidance to cause an underestimate of their numbers.

Juvenile striped bass mortality estimates for 1975-1979 varied widely, with the high estimates for 1977 and 1979 attributed to emmigration from the sampling area in the early fall (TI, 1981). The period used for those estimates was not consistent, however, beginning as early as 9 July in one year and as late as 27 August in another. It appears from the combined standing crop data of several years that the period from roughly early July to mid-August is one in which the mortality is variable and transitional between the high larval mortalities and the low juvenile mortalities of late summer. Another difficulty in assessing early summer mortality is that the population is undergoing recruitment to the sampling gear then. Assuming that recruitment occurs at around 30 mm, in 1982 it began in early July and continued through mid-August (Figure 5.1-1). Estimates of the juvenile standing crop during this time of year are therefore too low, making the mortality estimates for the July-October period too low as well.

5.2 WHITE PERCH

5.2.1 Growth

5.2.1.1 Larvae and Early Young-of-the-Year

Growth of larval and early juvenile white perch in 1982 was examined by the same method as for striped bass. Mean length was relatively stable during the ichthyoplankton sampling season. Recruitment to the yolk-sac stage was largely completed by the week of 7 June, after which substantially fewer eggs were collected and the numbers of yolk-sac larvae started to decline steadily. Although additional recruits comprised a moderate percentage of standing crop for two additional weeks (Table 5.2-1), the actual numbers were low because total standing crop decreased substantially after the week of 7 June. When Fall Shoals and Beach Seine sampling began in August, recruitment

TABLE 5.2-1. EGGS AND RECENTLY HATCHED LARVAE (<3.5 mm TL) AS A PERCENTAGE OF WHITE PERCH ICHTHYOPLANKTON STANDING CROP, HUDSON RIVER ESTUARY, 1982.

10-16 May	95%	14-20 Jun	14%
17-23 May	37%	21-27 Jun	6%
24-30 May	15%	28 Jun-4 Jul	1%
31 May-6 Jun	8%	5-11 Jul	1%
7-13 Jun	52%		

to the sampling gear was nearly complete (all fish caught from about mid-August onward were larger than the recruitment size of 25 mm), and the mean length for the population was approaching 50 mm (Figure 5.2-1).

The date when 60 mm was reached was estimated from both Fall Shoals and Beach Seine data, as the white perch juveniles were present in large numbers in both the shore zone and the offshore strata. The logarithmic growth curve estimated for the late summer-early fall period of reduced growth fitted the data well (r^2=.94), and estimated that 60 mm was reached on 8 September (curve A, Figure 5.2-1). This was well after the phase of rapid exponential growth, which probably ended just about when the first juvenile samples were collected (Figure 5.2-1). The midpoint of the first Fall Shoals sampling week, 12 August, was estimated as the end of the exponential growth phase. The mean length estimate of 44.3 mm for 12 August (from the logarithmic curve) and the mean length the week of 7 June (5.8 mm, when recruitment was approximately complete) were then used to estimate the growth curve for the period of exponential growth (curve B, Figure 5.2-1). This in turn provided an estimate of 25 July as the date when 25 mm was attained, and an average growth rate between 25 and 60 mm of 0.8 mm per day. Growth rate for the same length interval during 1973-1979 was estimated at 0.57 to 0.77 mm per day (TI, 1981).

The mean hatching date for white perch in 1982 was probably some time in late May. The pattern of egg abundance is an unreliable indicator because of the low and variable availability of the demersal eggs to plankton tows. The highest numbers of yolk-sac larvae occurred during the weeks of 17 and 24 May, although the week of 7 June was also high. If 5.8 mm during the week of 7 June is a reasonable representation of the population mean as assumed, then most hatching probably occurred roughly three weeks earlier. This estimate is based on the typical hatching length of 3 mm and the likelihood that the growth slows or pauses around the time of yolk absorption, as in striped bass, before entering the exponential phase. This would mean that growth from hatching to 25 mm averaged about 0.3 mm per day. For the 1973-1979

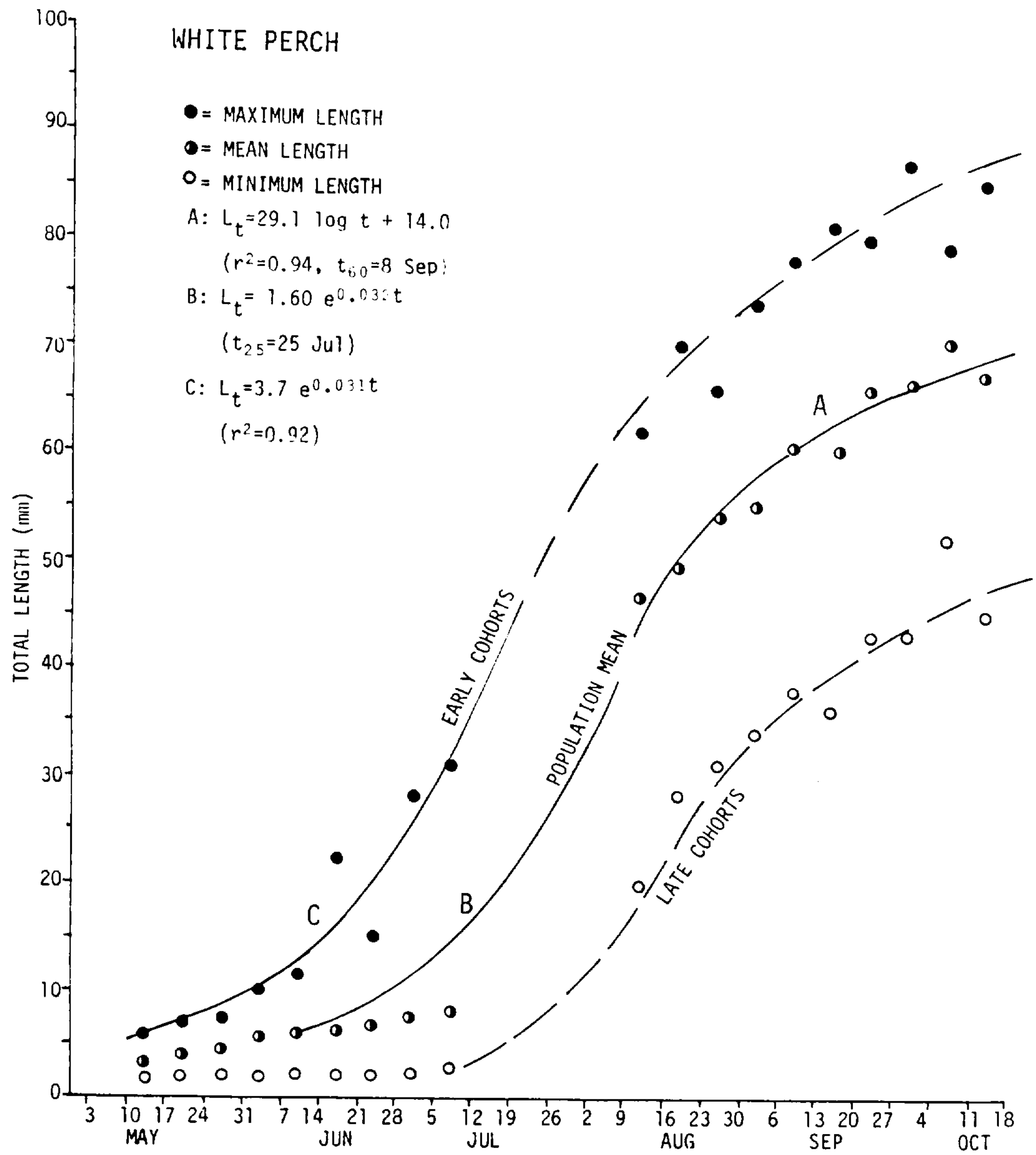


Figure 5.2-1. Growth of white perch larvae and early juveniles (mm TL) estimated from ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982. Solid lines are exponential and logarithmic curves fit by linear regression; dashed lines were drawn by eye.

period, the estimates of mean hatching date ranged between 16 May-13 June, and growth up to 25 mm at 0.45 to 0.85 mm per day (TI, 1981).

As seen for striped bass, the estimated times of hatching and reaching 60 mm in 1982 were fairly close to previous estimates, but the 1982 estimate of when recruitment length was reached was substantially later than earlier estimates. This can be attributed to overestimating the mean population length during July of earlier years by using sampling gear to which the population was not yet fully recruited. Estimation of the 1982 growth rate by following the maximum lengths representing the early cohorts (curve C, Figure 5.2-1) closely resembled the estimate produced from the mean lengths (Figure 5.2-1).

5.2.1.2 Young-of-the-Year

Juvenile white perch growth was approximately linear during mid-August through early October, with growth rate decreasing slightly during that period (Figure 5.2-2). Both Fall Shoals and Beach Seine survey data indicated growth of 0.4 mm per day. The reduction in the rate of increase in mean length is most noticeable in the last week of beach seine data, the week of 11 October. This may represent a reduction in growth rate alone, or it may also be influenced by a decrease in the proportion of larger fish in the shore zone as the fall offshore migration proceeds. During the late summer-early fall period, mean lengths in the shore zone lagged about one week behind those in the offshore strata, apparently indicating a slight preference by larger fish for somewhat deeper water.

5.2.2 Mortality

5.2.2.1 Larvae and Early Young-of-the-Year

Although length data are available for 1982, the length-frequency method of estimating mortality is inappropriate because

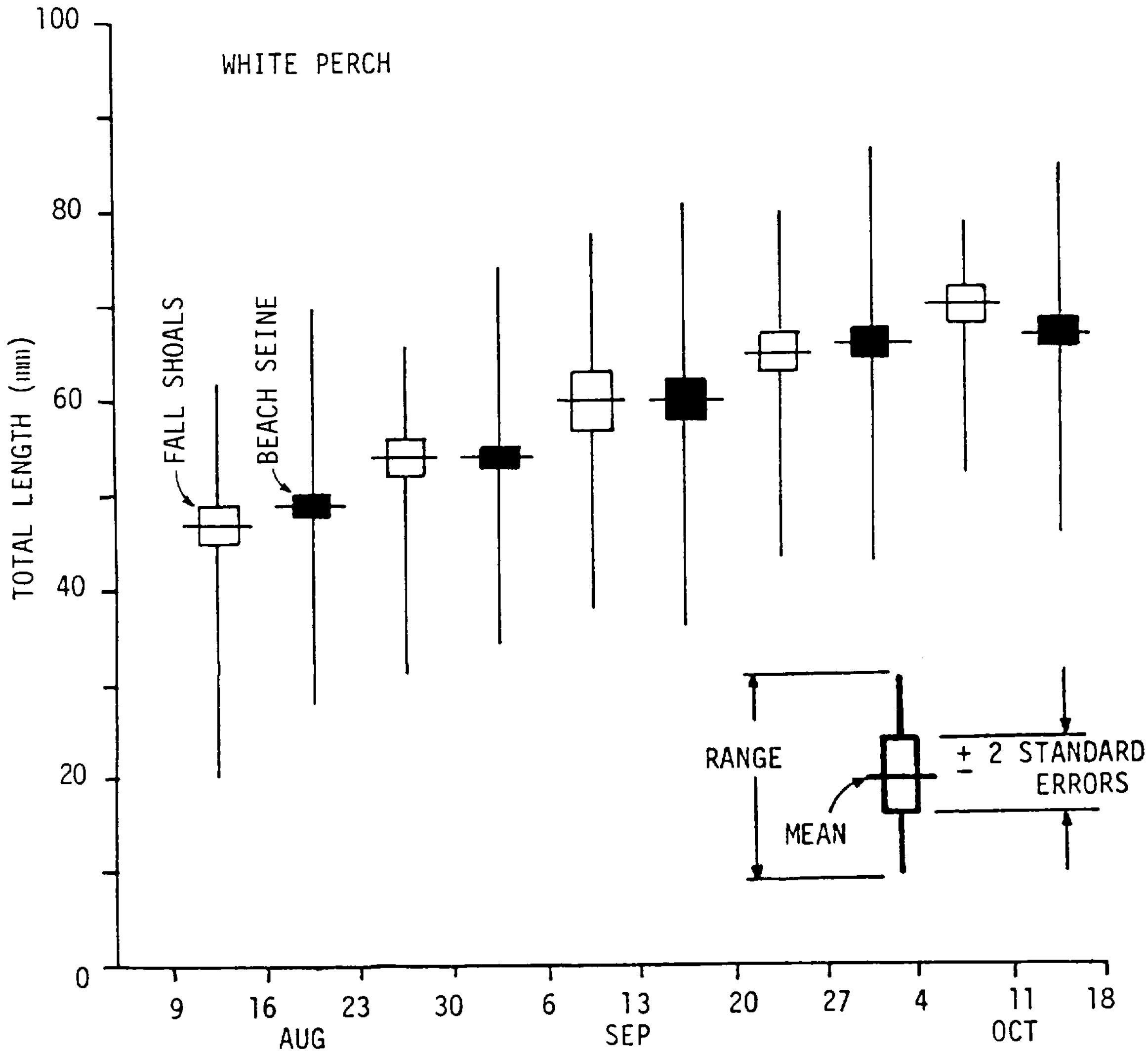


Figure 5.2-2. Growth of white perch juveniles (mm TL) estimated from Fall Shoals and Beach Seine surveys, Hudson River estuary, 1982.

sampling was discontinued when a large proportion of the population had not yet reached 20 mm (see Section 5.1.2.1). Limited data are available for estimating larval mortality from population estimates. Although recruitment to the yolk-sac stage appeared to be mostly completed by the week of 7 June, there was a secondary pulse in the standing crop three weeks later (Figure 5.2-3), which was primarily post yolk-sac larvae. There did not appear to be a corresponding pulse of yolk-sac larvae preceding that increase. This may indicate transport into the sampling area, possibly from tributary streams, or that a pulse of yolk-sac larvae may have gone undetected because small yolk-sac larvae are not fully recruited to the mesh size used for sampling. Using the week of peak standing crop plus the remaining four sampling weeks for estimating mortality by the population decline method, the resulting estimate is 5% per day. This is much lower than the 10-14% per day estimated for 1976-1979 (TI, 1981). Part of this difference is probably due to the late pulse of post yolk-sac larvae in 1982, making that estimate too low. The estimates for previous years were also based on a longer sampling season. The abundance in July of those years was probably underestimated because early juveniles are undersampled by the ichthyoplankton gear (as avoidance increases with growth), and by the Fall Shoals and Beach Seine gears (until fully recruited in mid-August). This is also suggested by the dip in the combined standing crop in late July (TI, 1981). The effect of these abundance underestimates is to increase the mortality estimate relative to an estimate (such as 1982) lacking July data. Probably 10% per day is a more realistic figure for post yolk-sac larval mortality, although it is most likely an overestimate for mid-through late July.

5.2.2.2 Young-of-the-Year

Mortality of white perch juveniles from mid-August to early October was 1.3% per day, based on the rate of decline in the weekly combined standing crop estimates. This was higher than the estimates for 1976-1979, which ranged from 0.2 to 0.9% per day, with 0.6% per day (1979) judged as the best estimate because of an expanded sampling

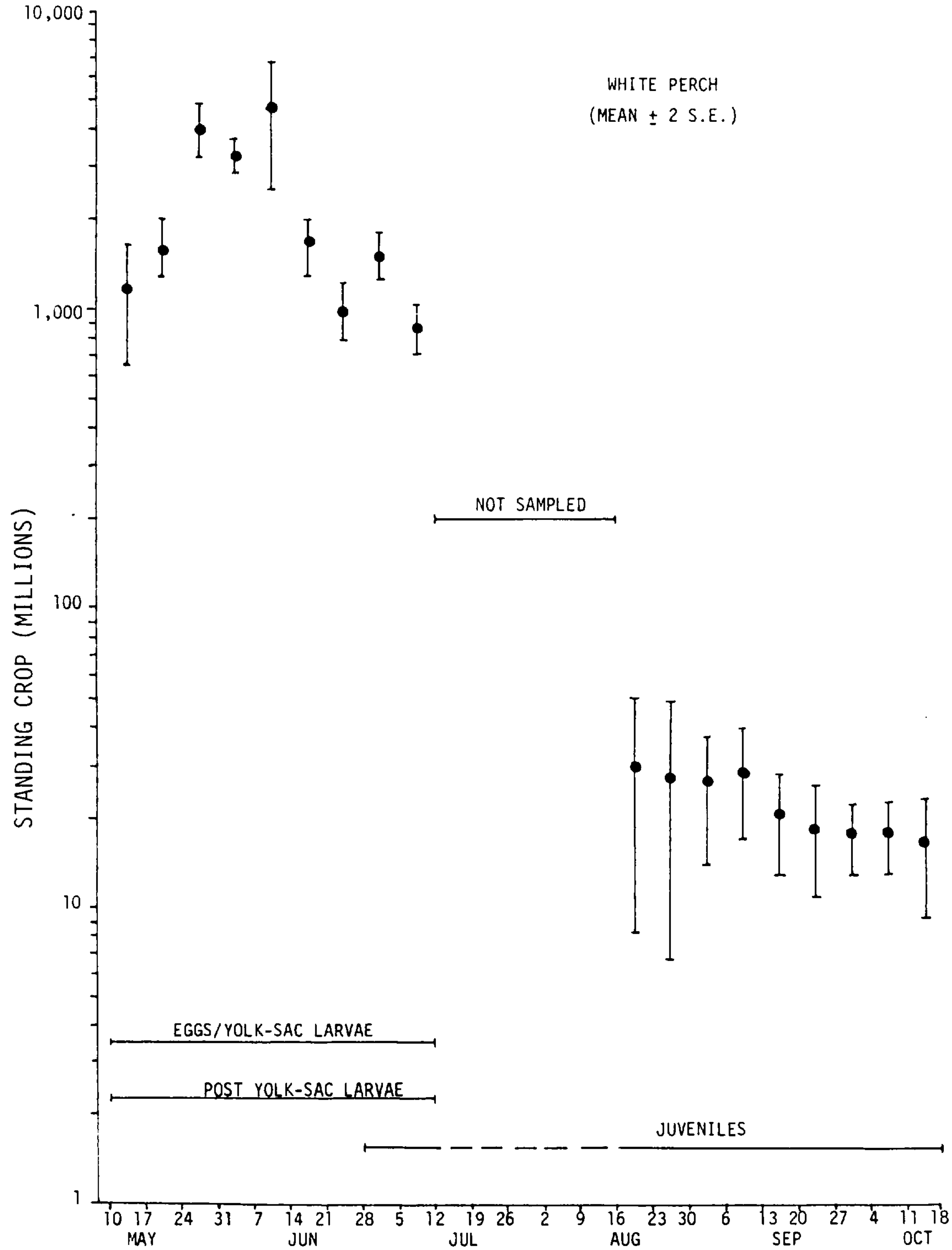


Figure 5.2-3. Standing crop of white perch early life stages, based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982.

program and revised gear efficiency data introduced that year (TI, 1981). Although the time intervals represented by those earlier estimates were not consistent, the results were in agreement in that mortality is substantially reduced from the larval stages. Similar to striped bass, white perch mortality had reached the phase of low and consistent mortality by the time juvenile sampling began in 1982.

5.3 AMERICAN SHAD

5.3.1 Growth

Growth of larval and early juvenile American shad was estimated by the same method as for striped bass and white perch. Recruitment to the plankton appeared to be complete by the week of 17 May when mean length was 11.2 mm, based on substantial reductions in the abundance of eggs and (particularly) yolk-sac larvae (Appendix B, Tables B-23 and B-24) as well as a reduction in the proportion of those stages in the total standing crop (Table 5.3-1) in subsequent weeks. Growth was assumed to be exponential from then until the week of 9 August when Fall Shoals sampling began. Mean length for that week was estimated at 71.0 mm from a logarithmic growth curve fitted to Fall Shoals and Beach Seine data (curve A, Figure 5.3-1). Exponential growth estimated from those two points (11.2 mm on 20 May and 71.0 mm on 12 August) closely followed the observed mean lengths during the seven remaining weeks (week of 24 May through week of 5 July) of the ichthyoplankton sampling (curve B, Figure 5.3-1). This suggests that either gear avoidance by shad may not be as strong as for striped bass and white perch, or growth of shad larvae is not interrupted by a phase of reduced growth.

TABLE 5.3-1. EGGS AND RECENTLY HATCHED LARVAE (<10 mm TL) AS A PERCENTAGE OF AMERICAN SHAD ICHTHYOPLANKTON STANDING CROP, HUDSON RIVER ESTUARY, 1982.

10-16 May	<99%	14-20 Jun	4%
17-23 May	24%	21-27 Jun	1%
24-30 May	15%	28 Jun-4 Jul	0%
31 May-6 Jun	17%	5-11 Jul	<1%
7-13 Jun	6%		

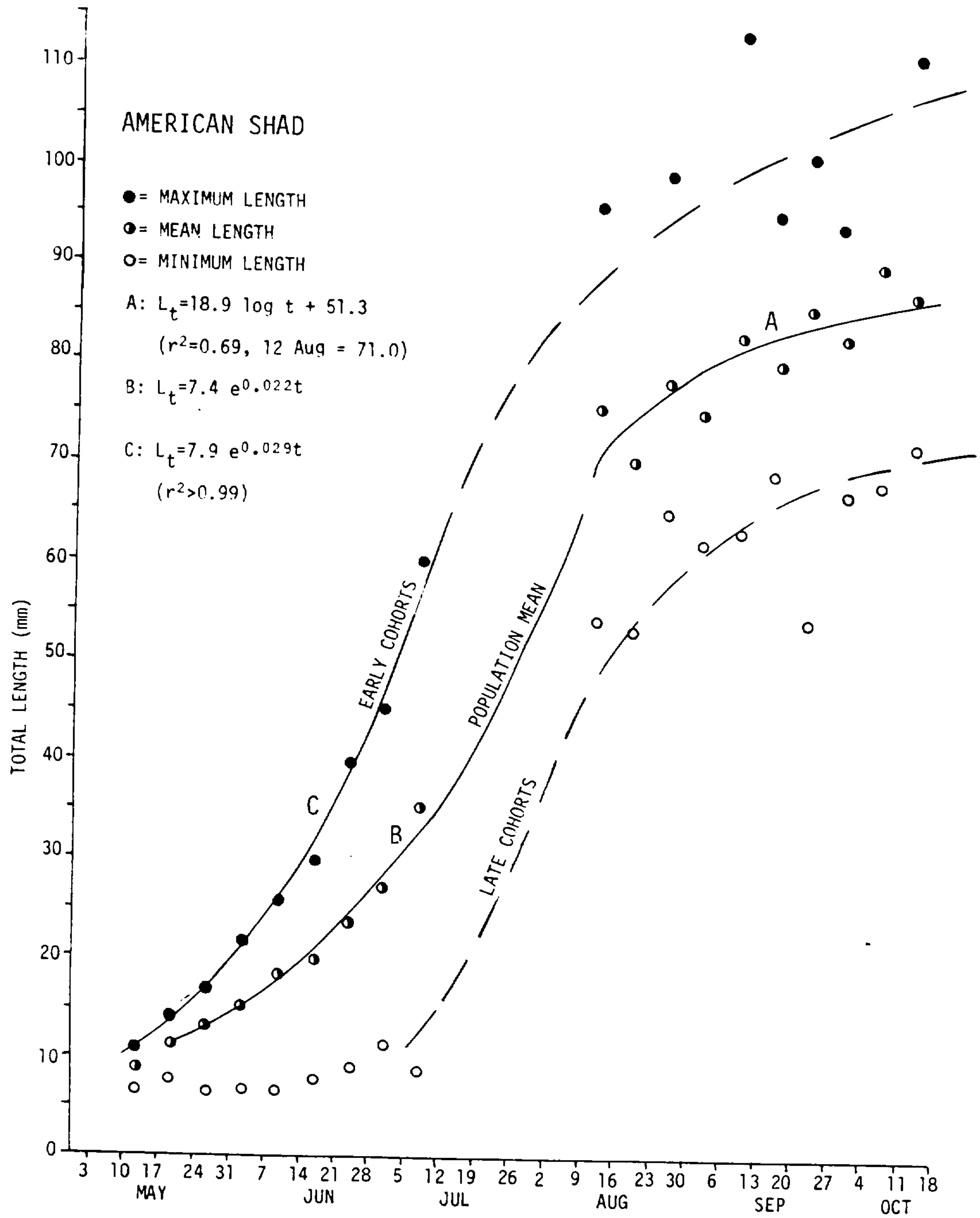


Figure 5.3-1. Growth of American shad larvae and early juveniles (mm TL) estimated from ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982. Solid lines are exponential and logarithmic curves fit by linear regression; dashed lines were drawn by eye.

During early August to mid-October, American shad juveniles grew about 0.3 mm per day in the shore zone and the offshore strata (Figure 5.3-2). The average length was consistently greater in Fall Shoals collections than in the Beach Seine survey, indicating a difference in depth preference related to size.

5.3.2 Mortality

Larval and early juvenile mortality cannot be estimated for American shad by the length-frequency method because sampling ended before larval and early growth was complete. Standing crop estimates were used for estimating mortality. From the week of 17 May, when recruitment was largely completed, through the last week of ichthyoplankton sampling, the population declined at a rate of 6% per day (Figure 5.3-3). This estimate can only be considered approximate, because (1) the time of recruitment was not sharply defined by the standing crop data, (2) the standing crop estimates did not produce a consistent pattern of decline during that period, and (3) some of the values were associated with relatively high standard errors.

Summer and early fall mortality was estimated from weekly combined standing crop data. Gear efficiency values were not available for incorporation in these data, but the distribution of American shad between the shore zone and the offshore strata was fairly consistent. Even though abundance is underestimated because of no gear efficiency correction, the pattern of weekly CSC should be valid. Recruitment to the juvenile surveys appeared to be complete by the first week of juvenile sampling based on the observations that (1) standing crop decreased after that week (Figure 5.3-3), and (2) minimum length data indicate that American shad had all reached 40 or 50 mm by then (Figure 5.3-1) which is larger than the recruitment length. Estimated mortality for August-October 1982 was 0.85% per day. As with striped bass and white perch, mortality of juvenile American shad had stabilized by midsummer to a rate substantially lower than it was during the larval stages.

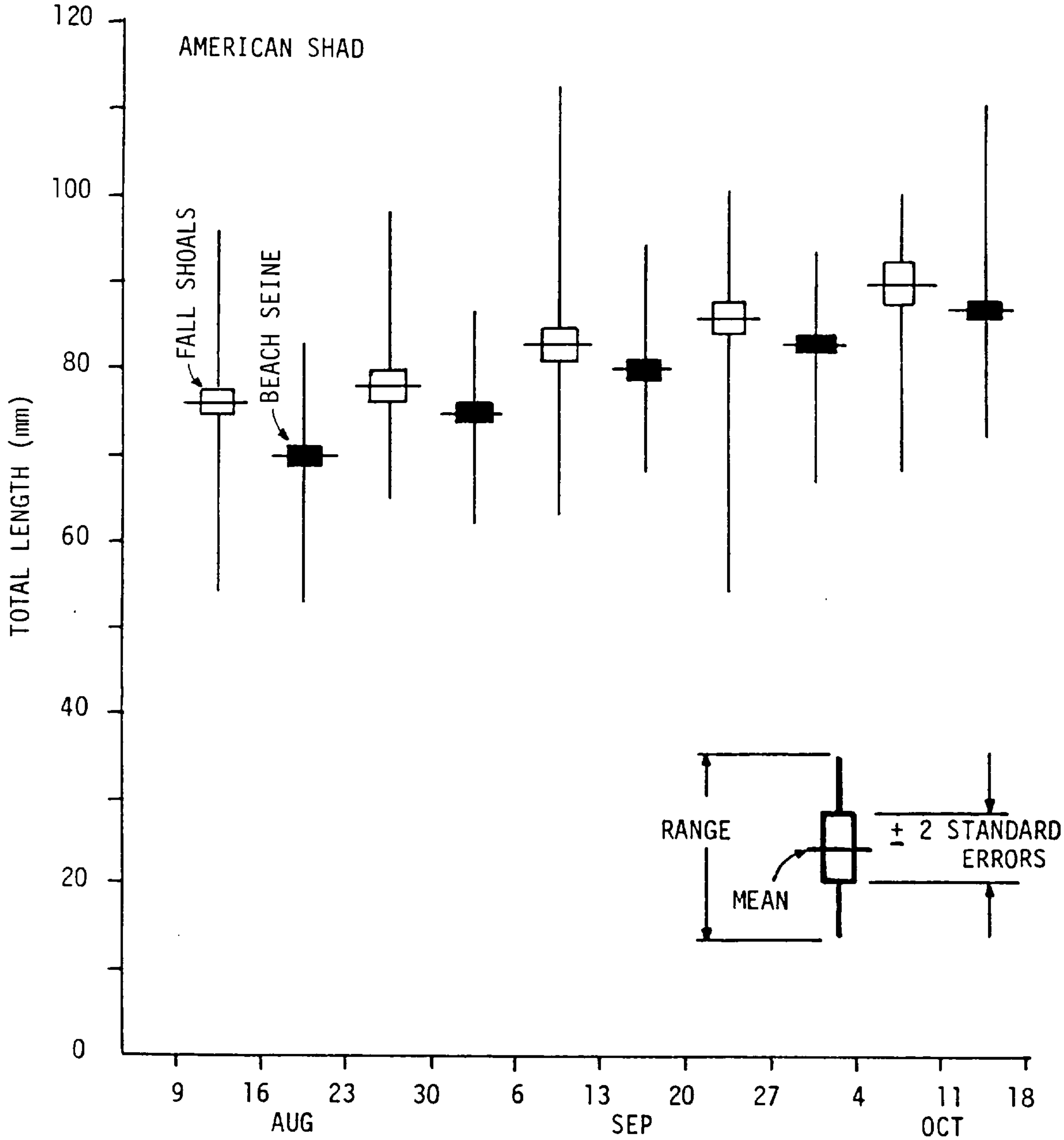


Figure 5.3-2. Growth of American shad juveniles (mm TL) estimated from Fall Shoals and Beach Seine surveys, Hudson River estuary, 1982.

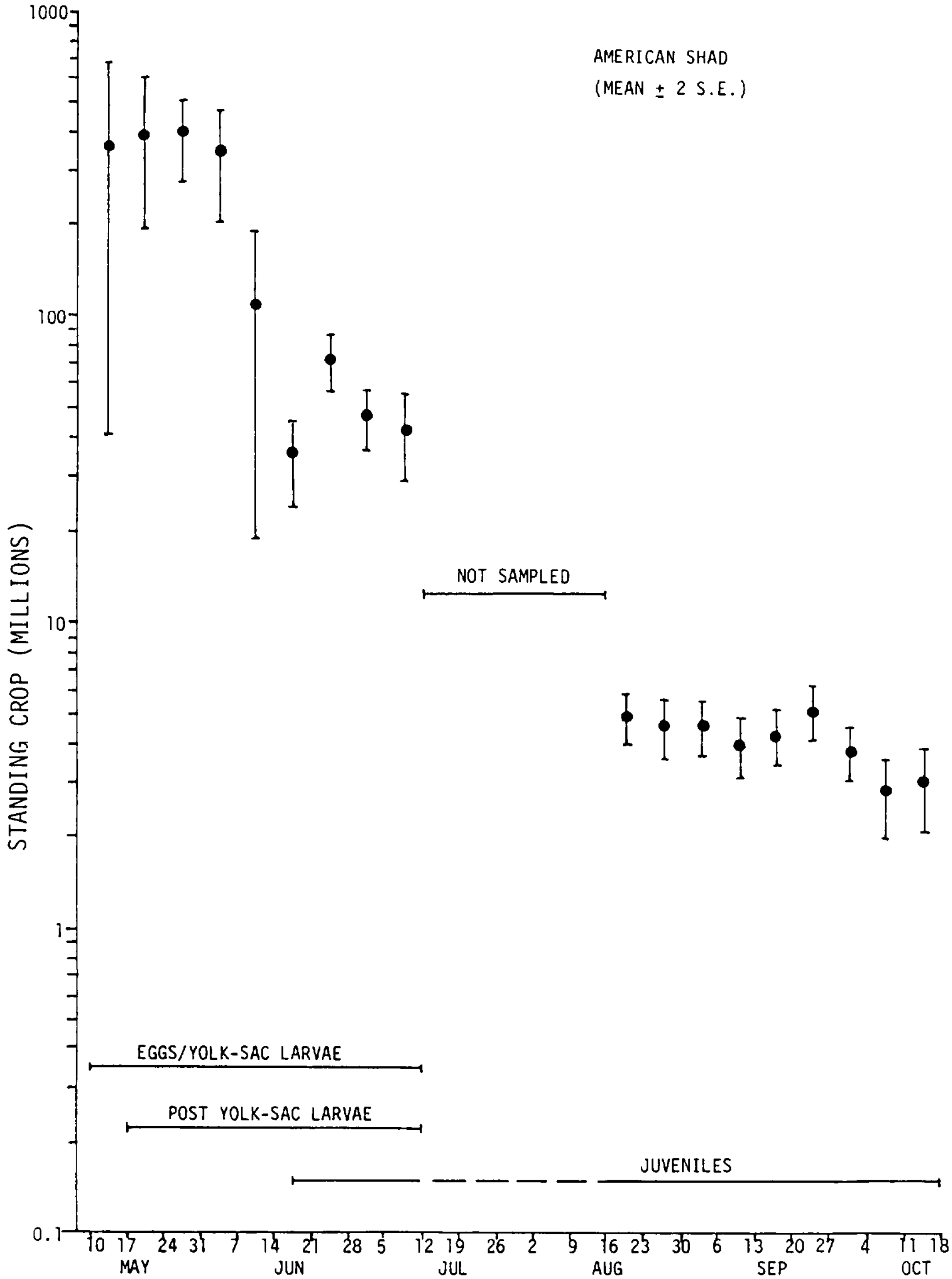


Figure 5.3-3. Standing crop of American shad early life stages, based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982.

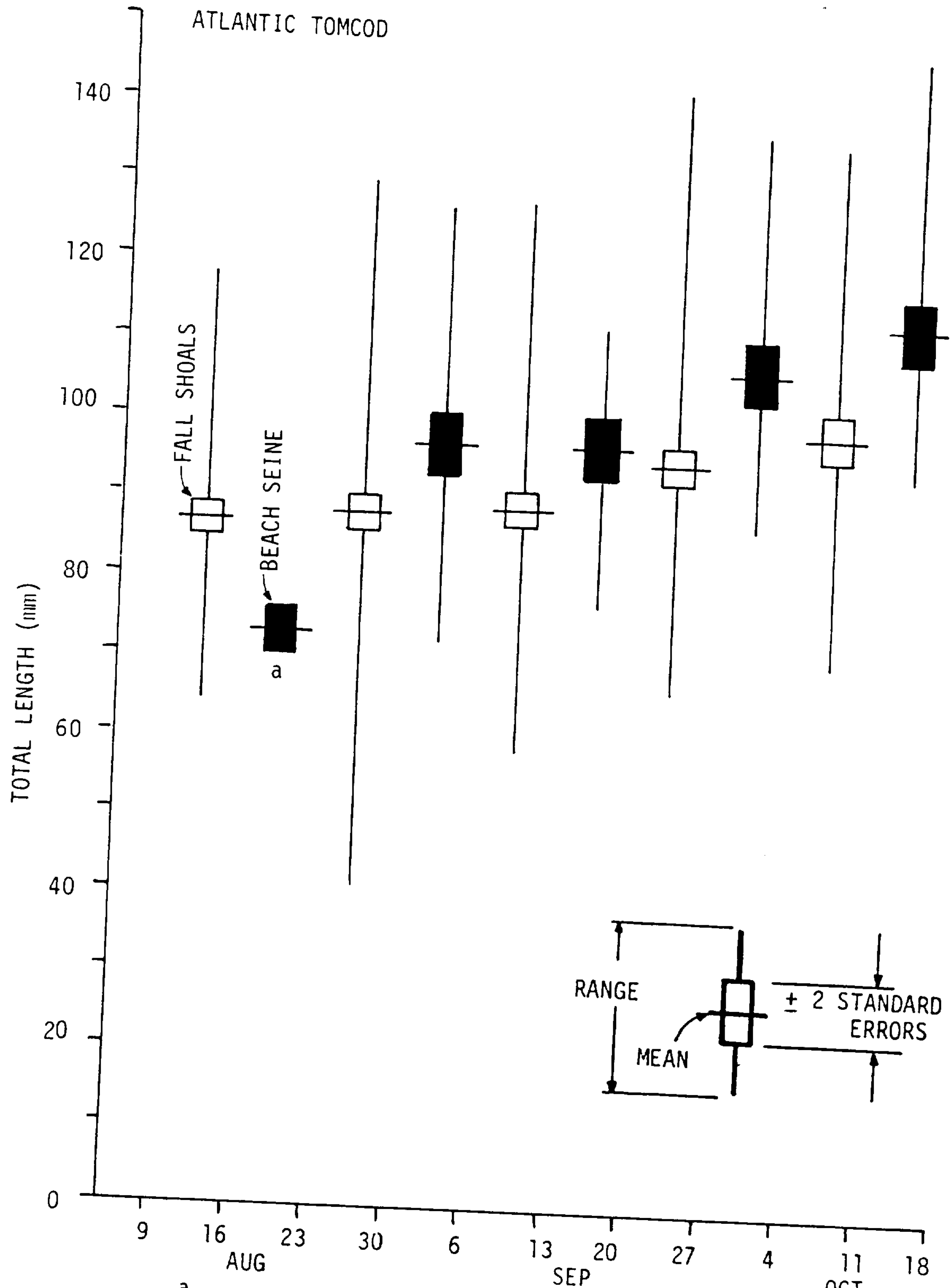
5.4 ATLANTIC TOMCOD

5.4.1 Growth

Since the Atlantic tomcod is a mid-winter spawner, growth of larvae and early juveniles in 1982 occurred prior to ichthyoplankton sampling. During the late summer-early fall juvenile sampling program, young-of-the-year tomcod grew from roughly 80 to 105 mm (Figure 5.4-1). In the Fall Shoals collections, representing the majority of the population, mean length increased 0.2 mm per day. Mean lengths in the shore zone were higher than in the offshore strata during September through mid-October (in August only two fish from the shore zone were measured). This pattern is the reverse of that seen for American shad, which were consistently larger in the offshore strata; and different from the pattern of striped bass lengths, which were initially higher but later were lower in the shore zone, compared to the deeper areas. Tomcod were mostly located in the bottom stratum. Larger individuals may move over greater distances, more often venturing into the shore zone than smaller fish, or larger tomcod may have an advantage over smaller ones enabling them to more successfully utilize those areas.

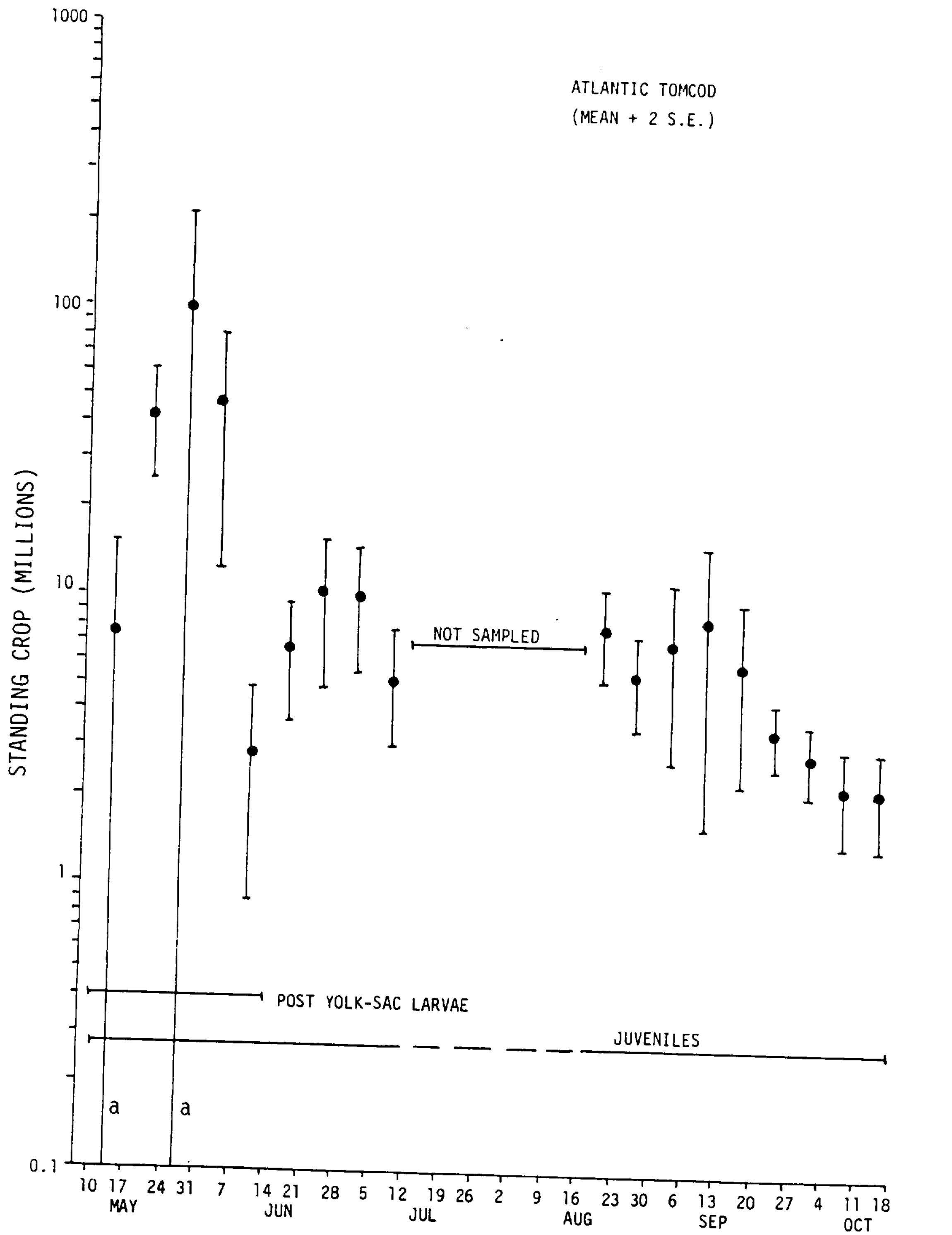
5.4.2 Mortality

Ichthyoplankton sampling in 1982 began after most Atlantic tomcod had entered the juvenile stage, so larval and early juvenile mortality cannot be estimated. Combined standing crop estimates, unadjusted for gear efficiencies (because they were not available), were utilized to examine the rate of population decline during mid-August through mid-October, which was estimated as 2.4% per day (Figure 5.4-2).



[a]Range < 4 S.E.

Figure 5.4-1. Growth of Atlantic tomcod juveniles (mm TL) estimated from Fall Shoals and Beach Seine surveys, Hudson River estuary, 1982.



a = Large standard errors are the result of the low number of specimens caught.

Figure 5.4-2. Standard crop of Atlantic tomcod early life stages, based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982.

5.5 BAY ANCHOVY

5.5.1 Growth

The 1982 ichthyoplankton season ended before the bay anchovy spawning season did, and length data were not collected. Bay anchovy spawning extends over a relatively long period of time, lasting from late May to late August in the Hudson River (Dovel, 1981). Growth is rapid, with some individuals of early cohorts even reaching sexual maturity the same summer in which they hatched (Hildebrand and Cable, 1930; Hildebrand, 1963). Because of this protracted spawning and rapid growth, there is a large variation in age and size among individuals at any particular time. This would complicate efforts to estimate growth rates for the phase of rapid growth during the larval and early juvenile stages even if length data were available.

Length data from the Fall Shoals and Beach Seine sampling show relatively little growth from mid-August to mid-October in terms of the population mean (Figure 5.5-1). In the offshore strata, which account for the bulk of the standing crop, the mean length first decreased between mid-and late August, and then began to increase at each of the three following biweekly sampling periods. This finding, and the fact that the weekly combined standing crops peaked in the first week of September (Figure 5.5-2), suggest that substantial recruitment was still occurring during August. Growth from late August to mid-October averaged 0.3 mm per day based on Fall Shoals samples.

In the shore zone, there was essentially no change from mid-August through the end of September. Only between the last two Beach Seine sampling periods did mean size increase appreciably (0.5 mm per day). Mean length in the shore zone was higher than in the deeper strata until about mid-September. This may indicate that bay anchovy tend to congregate in the shore zone only after they have reached a certain size.

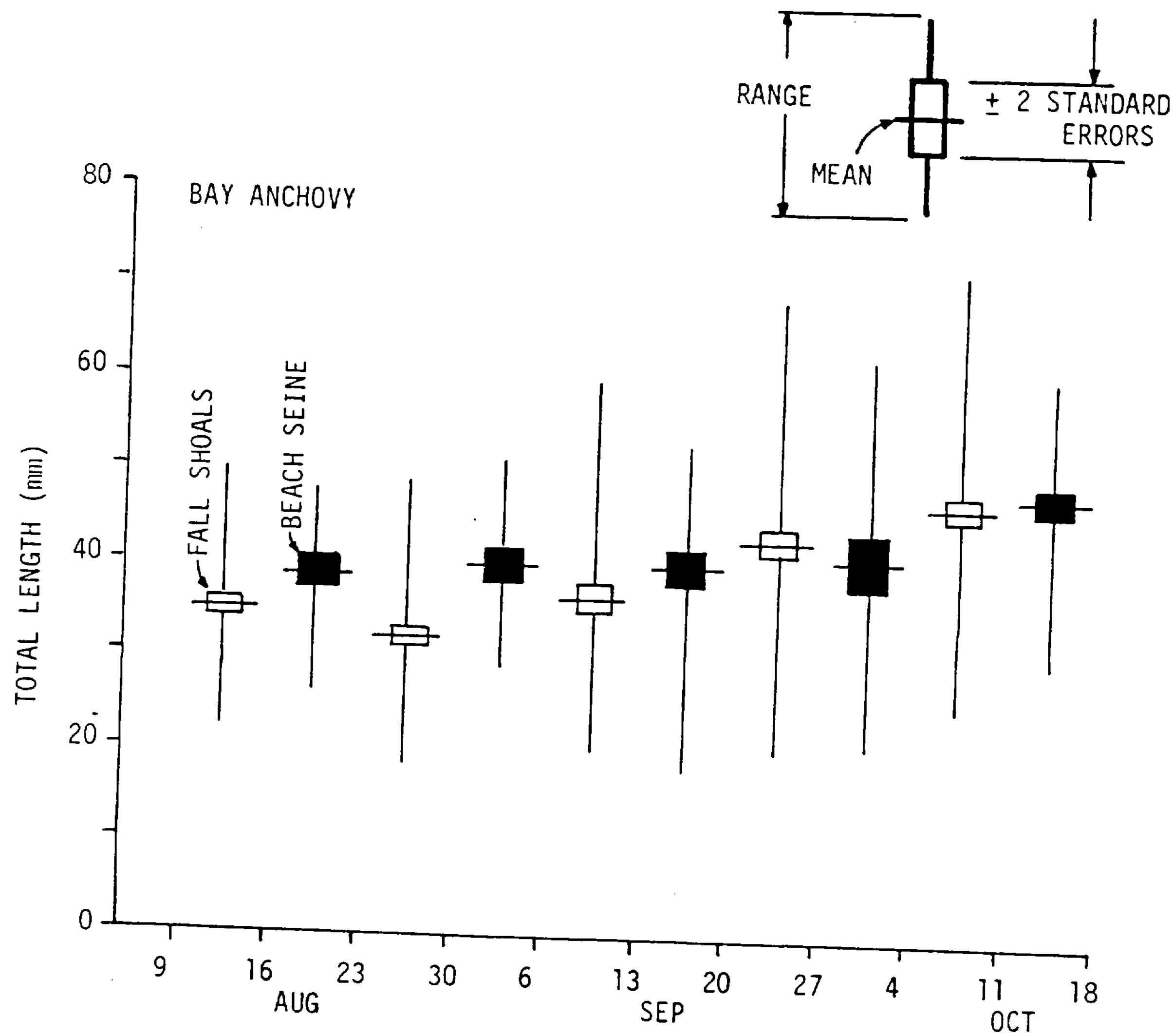


Figure 5.5-1. Growth of bay anchovy juveniles (mm TL) estimated from Fall Shoals and Beach Seine surveys, Hudson River estuary, 1982.

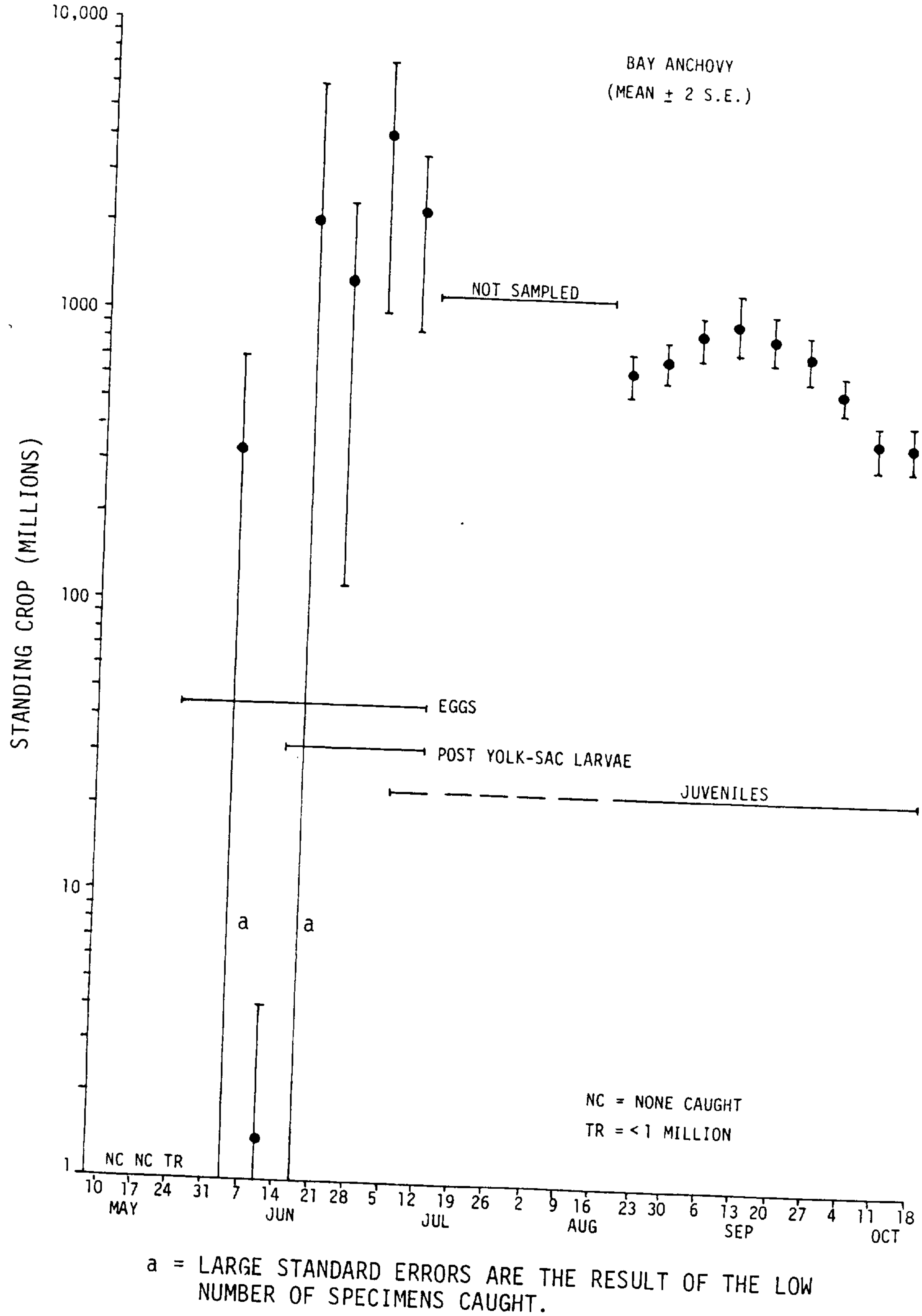


Figure 5.5-2. Standing crop of bay anchovy early life stages, based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1982.

5.5.2 Mortality

Because of the heterogeneity in age structure of the bay anchovy population, estimation of larval and early juvenile mortality would be difficult. After recruitment was complete in early September, the standing crop began to decline steadily, allowing an estimate of mortality to be calculated for the older fish (Figure 5.5-2). Although there would still be a substantial range of ages represented, those age differences would become proportionately less as the fish became older. Also, most if not all of the fish would have reached a point where mortality could be expected to be stabilized at a moderate level compared to the high mortality characteristic of the early stages of many fishes. The bay anchovy population in 1982 declined from early September to mid-October at a rate of 3% per day.

6.0 ANNUAL ABUNDANCE INDICES

Year class strength, or the number of fish produced in a single year's spawning season relative to those spawned in other years, can vary widely from year to year for a given species (Hjort, 1926). Striped bass, for example, exhibit wide variations in year class strength (Koo, 1970). Year class strength is believed to be established during the early life stages (Marr, 1956; Gulland, 1965; May, 1974). Since a dominant year class can make up a substantial proportion of the spawning stock over a period of several years, e.g. the 1973 striped bass year class (TI, 1981), detection of year class strength at an early age is an important contribution to the study of population dynamics and can be a useful management tool.

The relative strength of successive year classes of striped bass and white perch at the juvenile stage has been evaluated in previous year class reports by the combined standing crop index (CSC index), which is an estimate of the population size of young-of-the-year fish for the Hudson River estuary on 1 August. One of the objectives of this 1982 Year Class Report was to evaluate three aspects of the method of calculating the CSC index: (1) selection of the weeks to be used in the calculation, (2) the appropriateness of using the currently assumed mortality rate, and (3) feasibility of calculating confidence limits. Another objective was to develop a fall CSC index. This section first examines the questions of week selection and mortality rate. Then based on that evaluation a potential refinement of the method is presented for the summer CSC index. A fall CSC index is then developed, providing an additional indication of year class strength to supplement the summer index. The results of the current method and the alternate method are then compared using previous years' data. Then 1982 summer and fall CSC indices for striped bass and white perch are presented and discussed. Finally, the 1982 data are examined to develop confidence limits for the weekly CSC estimates and the annual CSC indices.

6.1 EVALUATION OF COMBINED STANDING CROP INDEX CALCULATION METHOD

6.1.1 Selection of Weeks Used to Calculate the Index

The CSC index for previous years (TI, 1981; Battelle, 1983) was based on the period immediately after recruitment to the Fall Shoals and Beach Seine Survey sampling gear was estimated to be complete, which was 1 August (TI, 1981). Standing crop estimates normally would be expected to increase until recruitment to a sampling gear was nearly complete (until it was less than mortality) and then decrease as a result of ongoing mortality. The actual weeks to be used in calculating the CSC index for a particular year were selected by visually inspecting a plot of the weekly combined standing crop to determine which week(s) constituted the peak. The CSC index was then estimated by extrapolating to 1 August using an exponential mortality curve.

In an attempt to eliminate subjectivity in visually selecting the weeks used to calculate the CSC index, Battelle (1983) evaluated several objective methods, such as selecting only the peak week, selecting all weeks greater than the mean, etc. Their conclusion was that all methods resulted in basically the same pattern among years despite some differences in the value of the index itself; therefore the visual inspection method was adequate. For this 1982 Year Class Report the possibility of a more objective method of selecting the weeks to be used in the CSC index was examined further. One technique which was considered was a mathematical curve-smoothing procedure (Tukey, 1977). However, application of this technique was not pursued further because inspection of weekly CSC data from several years indicated that other considerations needed to be addressed before deciding how best to select the week(s) to designate as the peak. One of these considerations is that in some years (e.g. 1980; Battelle, 1983) the peak standing crop occurred much earlier than 1 August, during a period when recruitment is undoubtedly far from complete. If weeks substantially prior to August are not used, assuming they would result in a biased (low) CSC index, then the early peak cannot be used. This results in a data set with no peak. A second consideration is that when a valid (post-recruitment) peak occurs, the number of weeks to be used to represent that peak must be determined. In past reports from one to four (usually two or three) weeks were used to represent peak CSC. In a few cases there are distinct peaks, for example white perch in 1978 and striped bass in 1979 when for two consecutive weeks the CSC was substantially higher than preceding and following weeks. In most cases, however, the peak is broad and poorly defined, so the number of weeks to be averaged is not clearly evident. A third consideration in selecting the week(s) to use in calculating the index is that the precision of the 1 August CSC index would probably be higher if the calculation were not based on such a small number of data points. This is particularly true since the standard error of the weekly CSC can often be relatively high around the first part of August compared to later months. For example, in 1977 the standard errors for the last week in July and the first two weeks in August were, on the average, five times as large as those from mid-August through mid-October (TI, 1980a).

On the basis of these considerations, (1) the appropriate weeks to include in the CSC index calculation cannot necessarily be determined by identifying the peak, e.g., if it occurs before recruitment is complete, and (2) the number of weeks to include is not always clearly evident, and possibly should not be limited to only one or very few. Therefore, the method which was chosen for further examination was to select a period of several weeks, rather than using only the peak weeks(s). The same period could be used for each year. The criteria defining the period are presented in Section 6.1.3.

6.1.2 Assumed Mortality Rate

Once the weeks to be used in calculating the CSC index had been selected, their geometric mean was converted to a 1 August equivalent by assuming exponential mortality of 0.00380 (0.379% per day or 75% per year). This value was based on the estimated mortality rates during approximately late July through early October, which ranged from 0.3 to

1.8% per day for striped bass and 0.2 to 10.7% per day for white perch (TI, 1981). Variation among years was high, and the lower values were considered to be the best estimates because (1) emigration of striped bass from the sampling area may inflate mortality estimates, (2) inaccurate gear efficiency values were used for years prior to 1979 for white perch (TI, 1981), and (3) a low mortality rate tends to underestimate population size when extrapolated to 1 August, therefore providing conservative population estimates which is a preferred approach for impact assessment.

In order to evaluate how closely the assumed mortality of 0.379% per day reflects actual mortality rates during the summer, one approach that was considered was a cohort growth simulation model. This approach, similar to that used by Boreman (1983) to model larval striped bass, would predict mortality from water temperatures during the period of interest, based on the relationship between temperature and growth rate. However, the data available from the literature were not extensive enough for the early juvenile period to establish the temperature-growth relationship needed for the model. Therefore, the best available mortality estimates for young-of-the-year striped bass and white perch in the Hudson River were considered to be those based on observed rates of decline in standing crop (Section 5.0 and earlier year class reports).

Estimates of mortality rate for the period around 1 August can be highly variable and the true mortality rate during that period is probably neither constant within a year nor consistent from year to year (Section 5.1). Although mortality rate is consistent and fairly low from late August through the end of September, using the observed mortality rate from this period to extrapolate the population estimate backward to 1 August probably underestimates the 1 August population. The longer the interval over which the extrapolation is made, the greater the underestimate would be. For example, if the August mortality was actually 3% per day, but the calculation assumed 0.38% per day, then a 1 August standing crop of 20 million would be underestimated by 3.4 million, 6.6 million, 9.2 million, and 11.2 million after intervals of one, two, three, and four weeks, respectively. If an extrapolation is made over a much longer interval, such as from November or December to 1 August, as has been done for white perch, then any error introduced by an inaccurate mortality estimate would affect the result substantially.

It can be concluded that (1) variability in mortality within a year and among years is high and (2) the error introduced by assuming an inappropriate value can be large. Because of these considerations it was assumed that the mortality observed for a particular year is the best estimate to use in extrapolating weekly CSC values for that year to a given date. A method by which this can be done is described in the next section (6.1.3).

6.1.3 Alternate Procedure

The intention of the combined standing crop index is to provide estimates of the year class strength of YOY striped bass and white perch and the contribution of each year's juveniles to the adult stock. The most accurate index for comparison of year class strength would be one calculated after the time of complete juvenile recruitment to the sampling gear and prior to any extensive emigration from the study area.

This section proposes a refinement of the past methods used in calculating CSC index for striped bass and white perch (TI, 1981; Battelle, 1983). To facilitate comparisons with previous year class reports, a summer CSC index is presented (Section 6.1.3.1). The calculation of a summer index is based on the premise that year class strength is established early in the juvenile stage (TI, 1981). In addition, a fall CSC index is presented (Section 6.1.3.2), with the intent of basing the CSC index upon a period of apparent stability in the juvenile population (i.e., mortality is relatively constant and immigration and emigration are low), and thus avoiding the early juvenile period when mortality is generally more variable.

6.1.3.1 Summer (1 August) Combined Standing Crop Index

The date by which virtually all of the new year class of striped bass and white perch has been recruited to the juvenile stage was estimated to be roughly 1 August (TI, 1981). Dispersal of a substantial proportion of the population from the study area apparently does not occur before the end of September in most years as evident in the gradual decline in the shore zone standing crop observed for 1974 through 1978 (TI, 1981). In some years substantial emigration may have occurred earlier. In 1979, for example, the shore zone standing crop decreased suddenly in late August (TI, 1981). This was interpreted as the result of part of the population migrating downriver and out of the sampling area, although the results of six years of tag returns for YOY striped bass did not show a downriver migration (TI, 1981). Another indication that extensive emigration does not usually occur that early is that in most years, the rate of decrease in the weekly CSC values was less in September than in August. If emigration of substantial numbers of juveniles began as early as late August, it would most likely have the opposite effect: weekly CSC values should decrease at a faster rate in September after emigration had begun. Therefore, the most appropriate data for determining the summer CSC index were assumed to be the weekly combined standing crop estimates from the beginning of August through early October. Specifically, the period selected was the 10-week period beginning with the week containing 1 August. CSC estimates for weeks earlier than 1 August would probably be too low because of incomplete recruitment, and estimates later than early to mid-October would probably be too low because of increasing emigration from the sampling area. It is possible that substantial emigration occurs earlier than assumed here. Without more information on actual movements of fish, the effects of mortality and emigration on the standing crop cannot be separated. The mid-point of each week was converted to the number of days after 1 August (setting 1 August equal to day zero). Then a population curve assuming exponential mortality was fit to the 10 points (weekly CSC values) by linear regression, using the same procedure by which mortality was estimated (Section 5.0 and Appendix A, Equation 24 with t = days after 1 August and N_o = regression intercept).

This makes extrapolation to 1 August unnecessary since the y-intercept of the regression line will be the 1 August estimate (CSC index).

Although the time period including 1 August through early October is used consistently for this presentation, a more accurate index may be one in which year to year variations in the timing of recruitment and emigration are taken into account by adjusting the period used in calculating each year's CSC index. For example, (1) if increasing standing crop is observed during early August, then recruitment is not yet complete and the early August data should not be included in the calculation of the CSC index, as is illustrated in Section 6.1.4 using data from 1976, or (2) if a large decrease is observed before October, then a substantial emigration may have occurred and the data after the decrease are questionable. There is a variety of factors (e.g., temperature) which may affect the timing of these events by one or more weeks from year to year. This regression method of calculating the 1 August CSC index could be refined further if additional data were available to determine with greater confidence the timing of completion of juvenile recruitment and beginning of emigration.

6.1.3.2 Fall (15 September) Combined Standing Crop Index

In developing a procedure for calculating a fall CSC index, only data collected before mid-October were considered. Although late fall (November-December) data were used previously to calculate a fall CSC index for white perch (TI, 1981), sampling after 1980 has only been conducted as late as approximately the middle of October. The general temporal pattern of the combined standing crop appears to be similar from year to year for both striped bass (Figure 6.1-1) and white perch (Figure 6.1-2). During late July and much of August there is high variability in CSC. This is due to (1) the variability in the timing of complete juvenile recruitment, and (2) relatively high and variable mortality of these early juveniles. During the month of September, the juvenile population is relatively stable, and in early October the CSC generally decreases, probably due to migration out of the estuary.

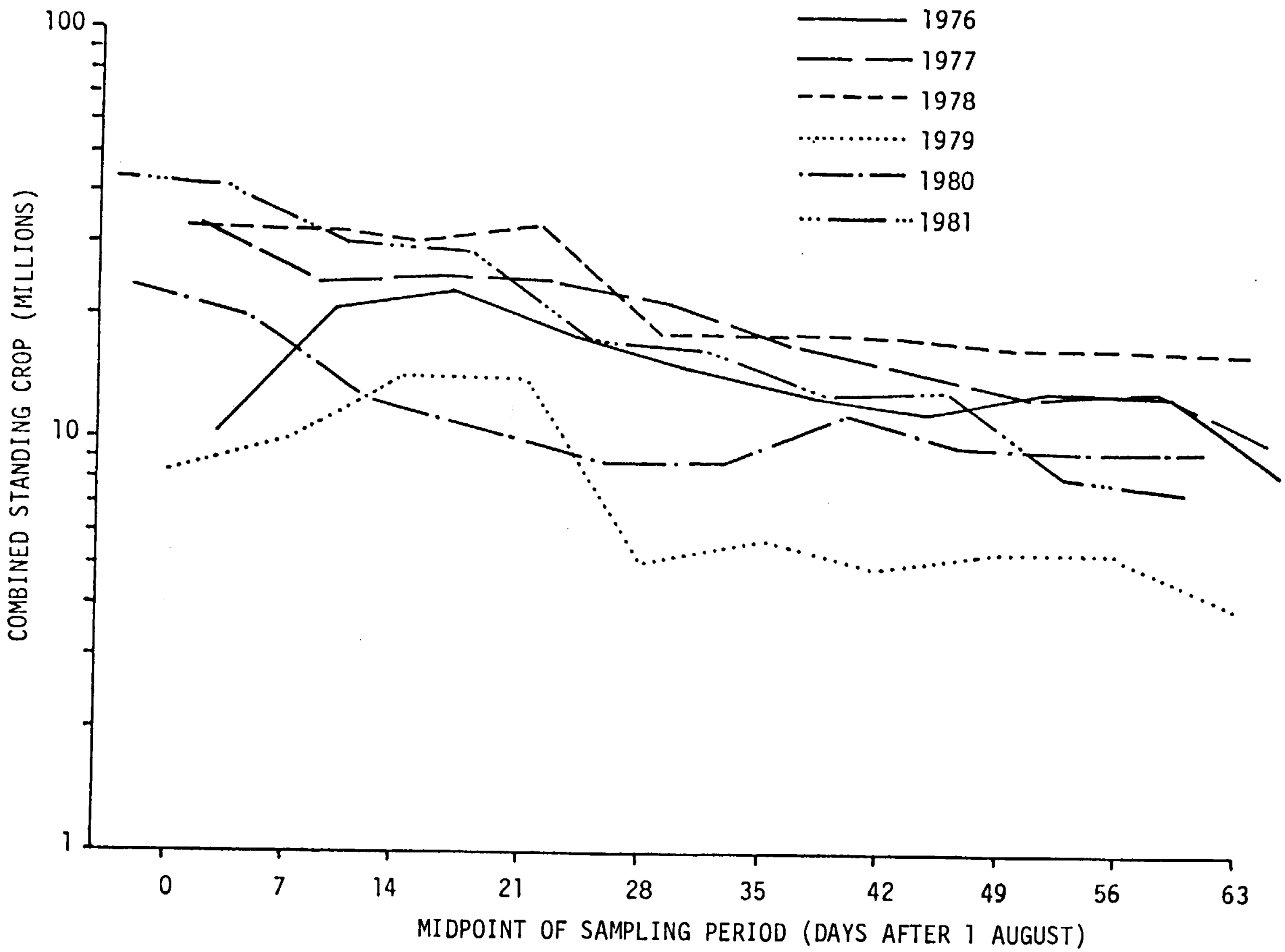


Figure 6.1-1. Population estimates of juvenile striped bass determined from the weekly combined standing crops during the period after complete recruitment (1 August) and before emigration (1 October), Hudson River estuary, 1976-1981.

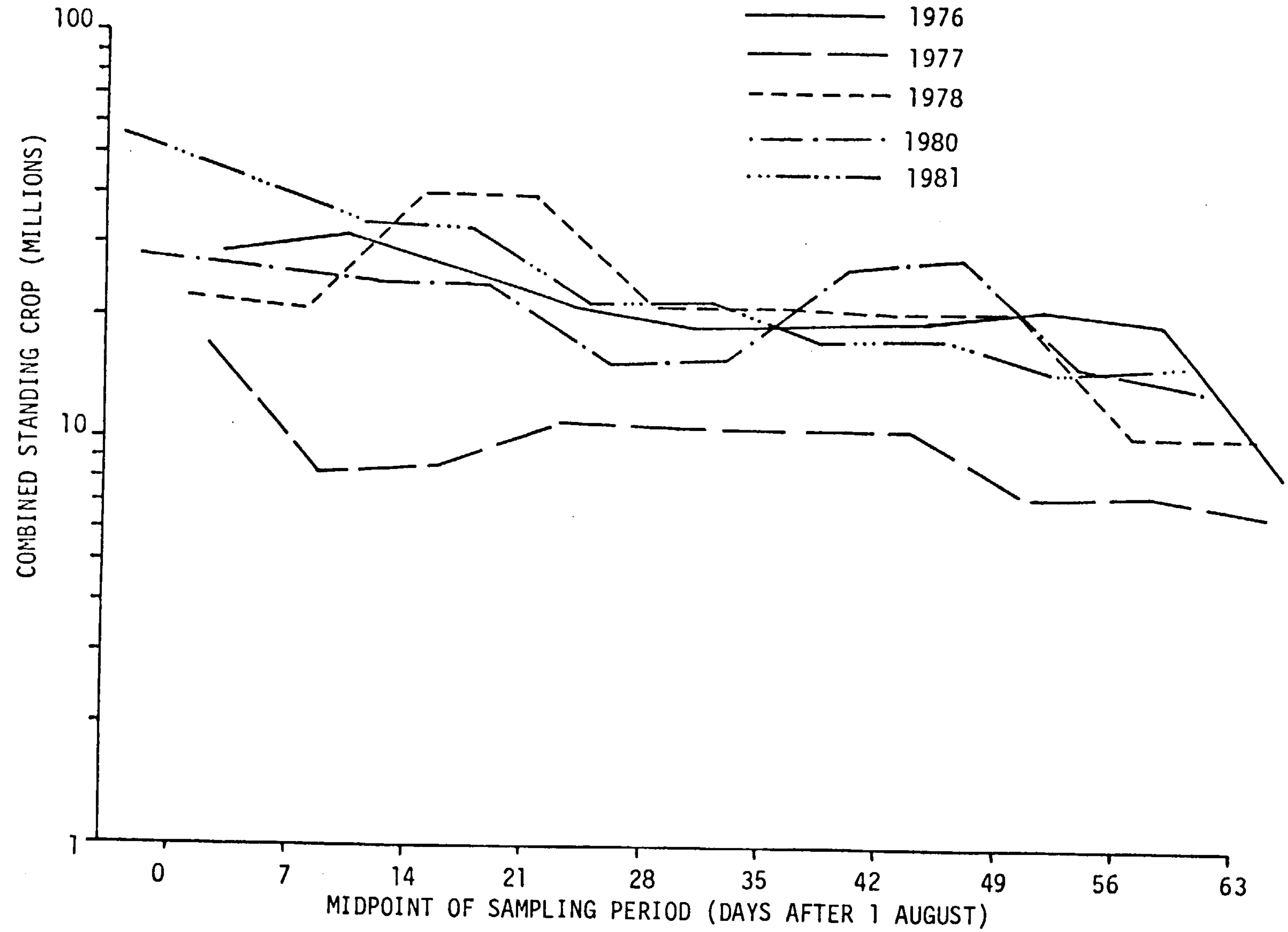


Figure 6.1-2. Population estimates of juvenile white perch determined from the weekly combined standing crops during the period after complete recruitment (1 August) and before emigration (1 October), Hudson River estuary, 1976-1981. (Weekly CSC data were not reported for 1979.)

Because of the relatively high rate of change in the size of the population in the early summer, an estimation of year class strength made later in the year when the population size is more stable (when mortality is relatively low and constant) should be more precise. Therefore the fall CSC index of year class strength was calculated utilizing this stable period, which for striped bass and white perch for the years 1976-1981 occurred predominantly during the month of September (28-63 days after 1 August).

The fall CSC index was calculated by the same regression procedure as the summer index, modified by (1) including only the September sampling weeks, and (2) defining the fall CSC index as the estimate produced by the regression for 15 September. Specifically, the weeks used were the five weeks beginning with the week containing 1 September. In those cases when the regression of the five CSC values was non-significant at $\alpha = 0.05$, then the value of the fall CSC index (15 September estimate) was calculated as the geometric mean of the five values. As with the summer CSC index, the exact period appropriate for computing the fall index may vary from year to year, due to variation in timing of recruitment and emigration. For example, the period after a major decline in combined standing crop would preferably not be incorporated, as this could be indicative of a movement of individuals from the study area.

6.1.4 Comparison of Alternate Procedure with Previous Calculations

Weekly CSC values for 1976-1981 were used to recalculate the CSC indices for those years using the regression method, for comparison with previously reported indices calculated using the peak method. Weekly CSC data from 1976-1978 were adjusted where necessary to reflect the same gear efficiency and day/night ratios used for the 1979-1981 data. The 1979 white perch CSC indices could not be calculated by the regression method because neither weekly CSC nor weekly standing crop by stratum data were reported for 1979 (TI, 1981).

Comparison of the summer CSC index calculated by the peak method (TI, 1981) and by the regression procedure presented in this section reveals that indices calculated by both methods agree closely (Tables 6.1-1 and 6.1-2). The rankings produced by the two procedures for striped bass are similar, identifying 1977, 1978, and 1981 as strong year classes. For white perch, the rankings are identical, indicating that 1976, 1978, and 1981 were strong year classes.

For 1976, the regression model and correlation coefficient for exponential regression of striped bass CSC index and days after 1 August are not significant ($P>0.05$) for the time period of 1 August through early October. Full recruitment of the juvenile stage appears to have occurred later than normal in 1976, based on a low CSC value for the first week in August compared to subsequent weeks. This may have been the result of water temperature, which during the early larval stages was observed to be the coldest in the six-year period (1976-81). Figure 6.1-3 compares two regression lines for 1976, the second line calculated after excluding the first week in August. When the period used in calculating the CSC index was changed to reflect full recruitment, the correlation coefficient and model became significant, while the CSC index changed only slightly, retaining the same ranking when compared to other years. This indicates that because several weeks are used in the calculation, the summer CSC index calculated by the regression procedure is relatively insensitive to the question of when recruitment is completed.

In previous years no fall index was calculated for striped bass. For white perch (Table 6.1-3), large differences in the results can be observed between the past method of calculating a fall CSC index and the method used in this report. The past method used peak weeks during November and December extrapolated to 1 August. During this late fall period, weekly combined standing crops often increase. For example, in 1977 the peak weekly CSC in November was approximately 8% higher than the peak weekly CSC during August (TI, 1980a), resulting in a fall CSC index (extrapolated to 1 August from the November peak) 78% higher than the summer CSC index for the same year.

TABLE 6.1-1. A COMPARISON OF SUMMER CSC INDEX OF STRIPED BASS AS CALCULATED BY THE PEAK METHOD AND THE REGRESSION METHOD.

	PEAK METHOD[a]	REGRESSION METHOD	
YEAR	SUMMER CSC INDEX	SUMMER CSC INDEX	CORRELATION COEFFICIENT[b]
1976	18.0 (5)[c]	18.6 (4)	-0.54[NS]
1977	34.0 (2)	33.2 (3)	-0.97**
1978	33.0 (3)	34.7 (2)	-0.89**
1979	12.0 (6)	11.8 (6)	-0.76*
1980	21.7 (4)	16.8 (5)	-0.78**
1981	42.5 (1)	42.5 (1)	-0.98**

[a] Sources: TI 1981 (1976-1979), Battelle 1983 (1980-1981)

[b] NS - Not Significant
 * - Significant $P \leq 0.05$
 ** - Highly significant $P \leq 0.01$

[c] Numbers in parentheses indicate relative strength of year class.

TABLE 6.1-2. A COMPARISON OF SUMMER CSC INDEX OF WHITE PERCH AS CALCULATED BY THE PEAK METHOD AND THE REGRESSION METHOD.

YEAR	PEAK METHOD[a] SUMMER CSC INDEX	REGRESSION METHOD SUMMER CSC INDEX	REGRESSION METHOD CORRELATION COEFFICIENT[b]
1976	31.0 (3)[c]	32.8 (3)	-0.78**
1977	18.0 (5)	12.6 (5)	-0.65*
1978	32.0 (2)	34.1 (2)	-0.70*
1979	47.0	--[d]	
1980	23.0 (4)	26.9 (4)	-0.59[NS]
1981	35.0[e] (1)	45.4 (1)	-0.97**

[a]Sources: TI 1981 (1976-1979), Battelle 1983 (1980-1981).

[b]NS - Not significant
* - Significant P ≤0.05
** - Highly significant P ≤0.01

[c]Numbers in parentheses indicate relative strength of year class, for years in which the index could be calculated by both methods.

[d]Original data not reported

[e]Alternate value for 1981 using different weeks than for first estimate was 49.0 (Battelle, 1983).

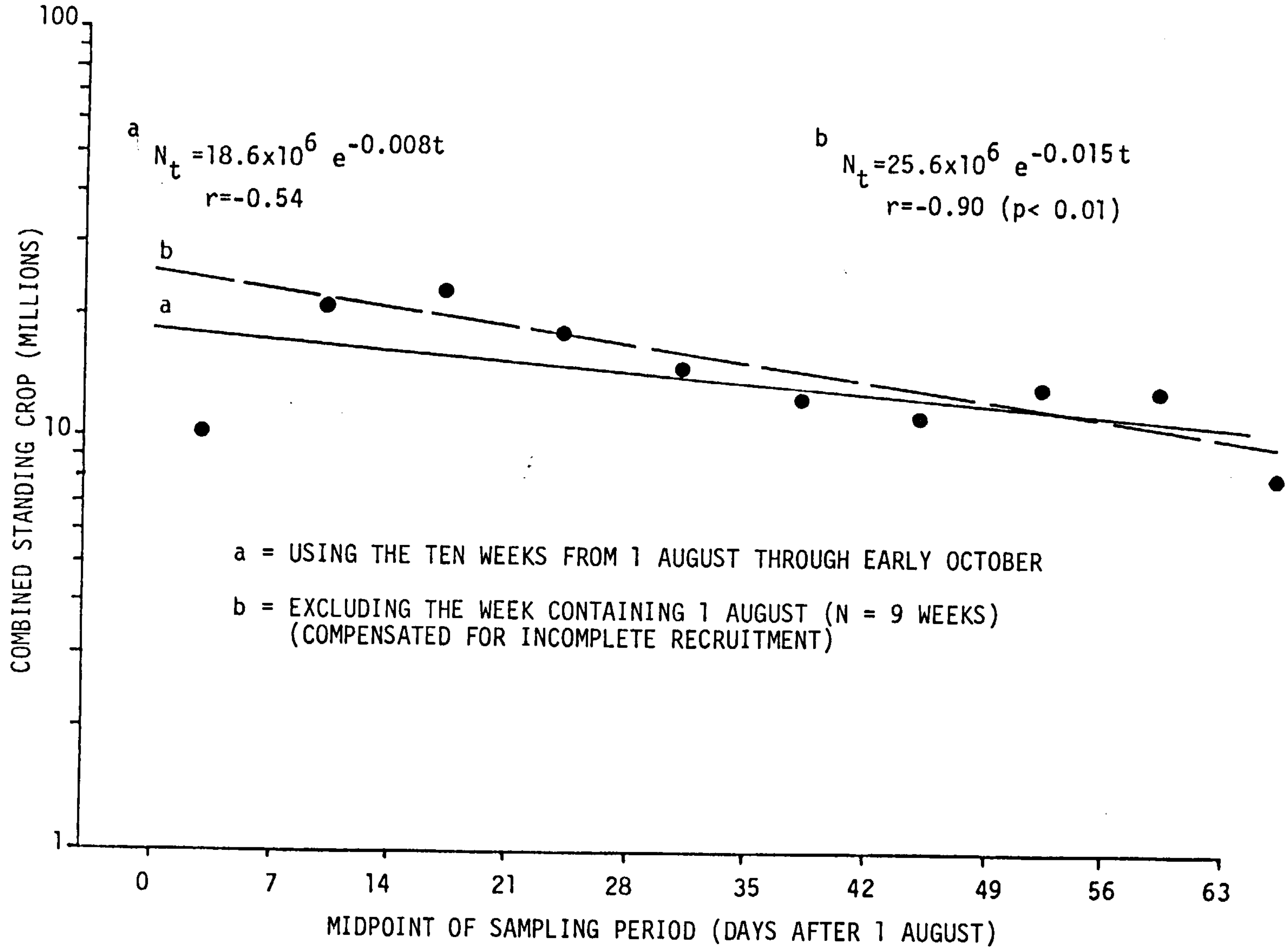


Figure 6.1-3. Results of the exponential regression analysis of striped bass weekly combined standing crops to determine the summer (1 August) CSC index for the year 1976, Hudson River estuary.

TABLE 6.1-3. A COMPARISON OF FALL CSC INDEX OF WHITE PERCH AS CALCULATED BY THE PEAK METHOD AND THE REGRESSION METHOD.

	PEAK METHOD[a] FALL CSC INDEX	REGRESSION METHOD[b] FALL CSC INDEX
1976	28.0 (2)[c]	20.0 (1)
1977	32.0 (1)	9.3 (4)
1978	21.0 (3)	18.4 (3)
1979	39.0	--[d]
1980	15.0 (4)	19.1 (2)
1981	--[e]	17.7

[a]Sources - TI 1981 (1976-1979), Battelle 1983 (1980-1981)

[b]Correlation coefficient was non-significant in each case ($p > 0.05$), therefore the index was calculated as a geometric mean rather than a regression estimate.

[c]Numbers in parentheses indicate relative strength of year class, for years in which the index could be calculated by both methods.

[d]Original data not reported

[e]Not calculated due to limited sampling

It is unknown whether the apparent increase in the population in the late fall is due to (1) immigration into the sampling area, (2) movements among strata affecting the estimate because of differences in gear efficiency factors or seasonal changes in gear efficiency, or (3) some other factor(s). This uncertainty, together with the unavailability of late fall data after 1980, supports the use of a September rather than a November CSC index for white perch.

Due to the variability in mortality that occurs during the early juvenile stages, the fall CSC index appears to be preferable to the summer CSC index because it is based upon a juvenile population that is stable with respect to mortality and movements. A fall CSC index should give a more precise estimate of fish available for recruitment to the adult stock, and any variation in this index between years should allow a more accurate understanding of the adult population dynamics in the Hudson River estuary.

The evaluation of the method of calculating the CSC index can be summarized by the following points: (1) Selection of weeks to be used, if based only on peak values, can be difficult if a peak occurs before recruitment is complete or if the peak is not sharply defined. (2) An assumed mortality rate based on a long-term average may not accurately reflect mortality for a particular year, especially in the early summer. (3) Calculating the index by regression of several weeks of CSC values avoids the above problems and has the additional advantages of being simpler and more objective than the current (peak) method. (4) The extent to which emigration from the sampling area may affect the results of the regression method is unknown. (5) The regression and peak methods of calculating a summer index produce similar results. (6) Relative year class strength indicated by the proposed fall CSC index agrees well with the summer index calculated by either procedure. (7) Relative year class strength indicated by the fall CSC index calculated for white perch by the peak method does not agree well with either the proposed fall index or the summer index calculated by either procedure.

In general, the alternate procedure examined here (the regression method) reduces the subjectivity involved in selecting the weeks to use in calculating the CSC index, while producing results consistent with the summer index calculated by the previously used peak method. The primary reservation in using the regression method is the question of whether the inclusion of late summer-early fall data introduces a bias due to emigration from the sampling area. Although previous tag return data and a relatively stable population level during September would seem to discount emigration as a major bias, additional data to support this contention would be desirable. One way to test for emigration would be additional tagging studies in which areas adjacent to the sampling area were sampled (i.e., below the Yonkers region and in coastal waters near the mouth of the Hudson River). A tagging program for this prupose would have to be of sufficient magnitude to quantify emigration in relation to the time of year (e.g., two-week intervals). Another question, which affects both the peak and the regression methods, is to what extent incomplete recruitment during early August can affect the value of the CSC index. This could be investigated by the use of a finer mesh in the sampling gear during that period.

6.2 STRENGTH OF 1982 YEAR CLASS

6.2.1 Striped Bass

The 1982 sampling did not begin until after the striped bass population had reached the phase of low late summer mortality (Section 5.1.2.2). Mortality in early August of 1982, based on observations in past years (TI, 1981; Battelle, 1983), was undoubtedly higher than from mid-August through mid-October, when mortality was negligible (Figure 5.1-3). Therefore, extrapolating the CSC values during mid-August to mid-October back to 1 August would underestimate the actual 1 August population. Comparison of such an estimate with 1 August estimates from previous years would be questionable. In this case, neither the peak method nor the regression method can provide an adequate 1 August estimate.

For this reason, as well as the advantages of a fall CSC index discussed in Section 6.1.3.2, the strength of the 1982 year class of striped bass was evaluated by the fall CSC index. This was compared to a fall index of previous years (1976-1981) and to the summer CSC index of previous years as presented in Section 6.1.3 (Figure 6.2-1). Based on the fall CSC index of 10.4 million, the 1982 striped bass year class was approximately as large as that of 1981, which was the largest year class since the low year class of 1979. The 1982 year class was also considered to be strong by the New York State Department of Environmental Conservation (Young, 1983).

The large difference between the 1981 fall and summer CSC indices, a 73% decrease compared to 50% or less in other years, is apparently due to either a high mortality continuing longer than normal in 1981 or emigration from the sampling area during late summer-early fall (Figure 6.1-1). This suggests that relative year class strength may not always be determined as early as the beginning of August, and is a possible indication that a fall CSC index should be used to evaluate year class strength.

6.2.2 White Perch

As with striped bass, samples were not collected in 1982 during the time that juvenile CSC was historically the highest (early August). The lack of the first three of the ten weeks which would be used to calculate the summer CSC index could therefore affect (1) the precision of the index, because fewer data points are available for the estimate, and the missing ones are those closest to the desired estimate, and (2) the accuracy of the index, because of potential bias introduced by excluding the period when mortality was likely to be highest. This summer index is at best a tentative estimate and is used only with reservation in judging the 1982 year class strength relative to that of previous years. According to the white perch summer and fall CSC indices (39.0 million and 22.1 million respectively), 1982 was at least as strong a year class as 1976, 1978, 1980 and 1981, and definitely stronger than the weak 1977 year class (Figure 6.2-2).

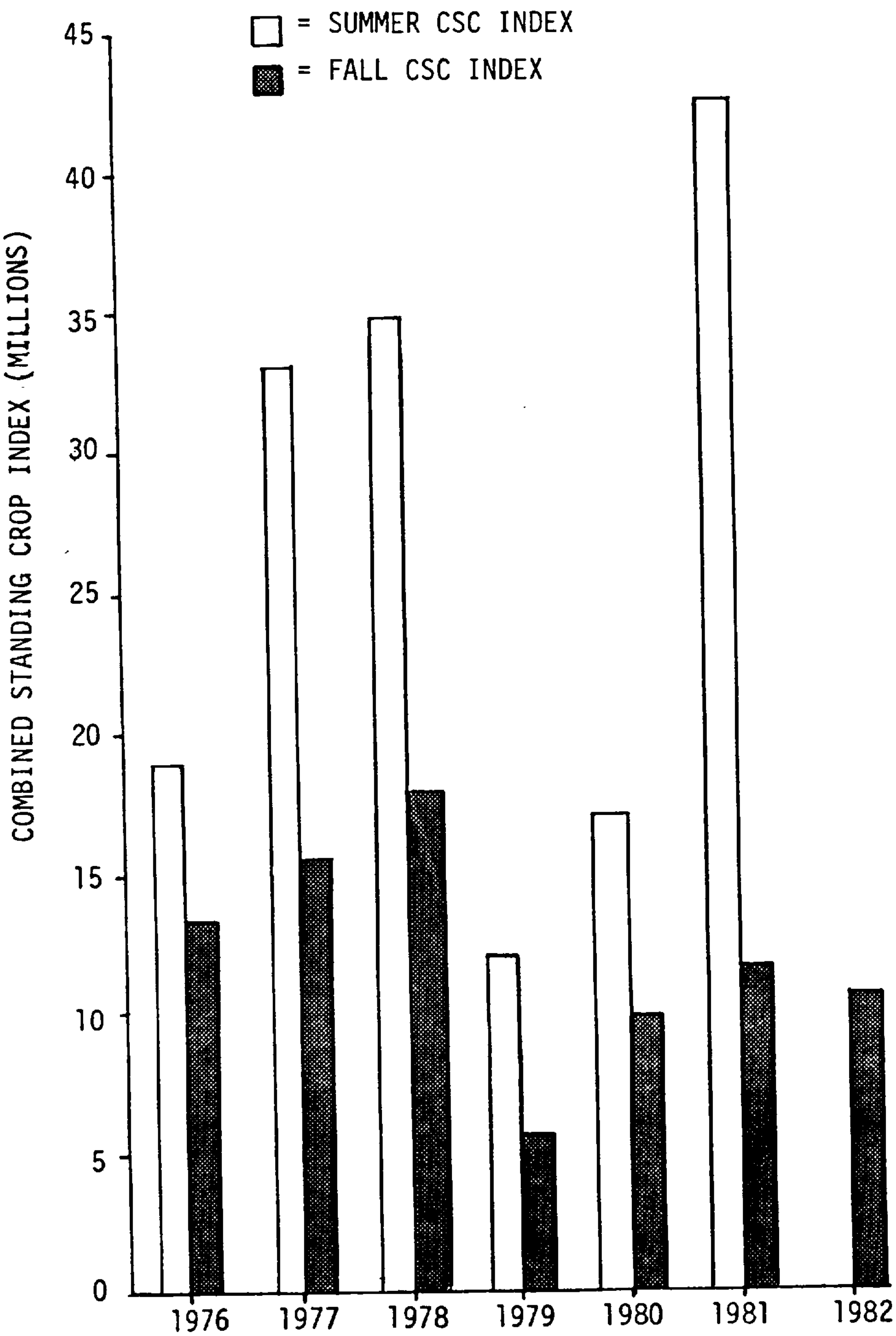
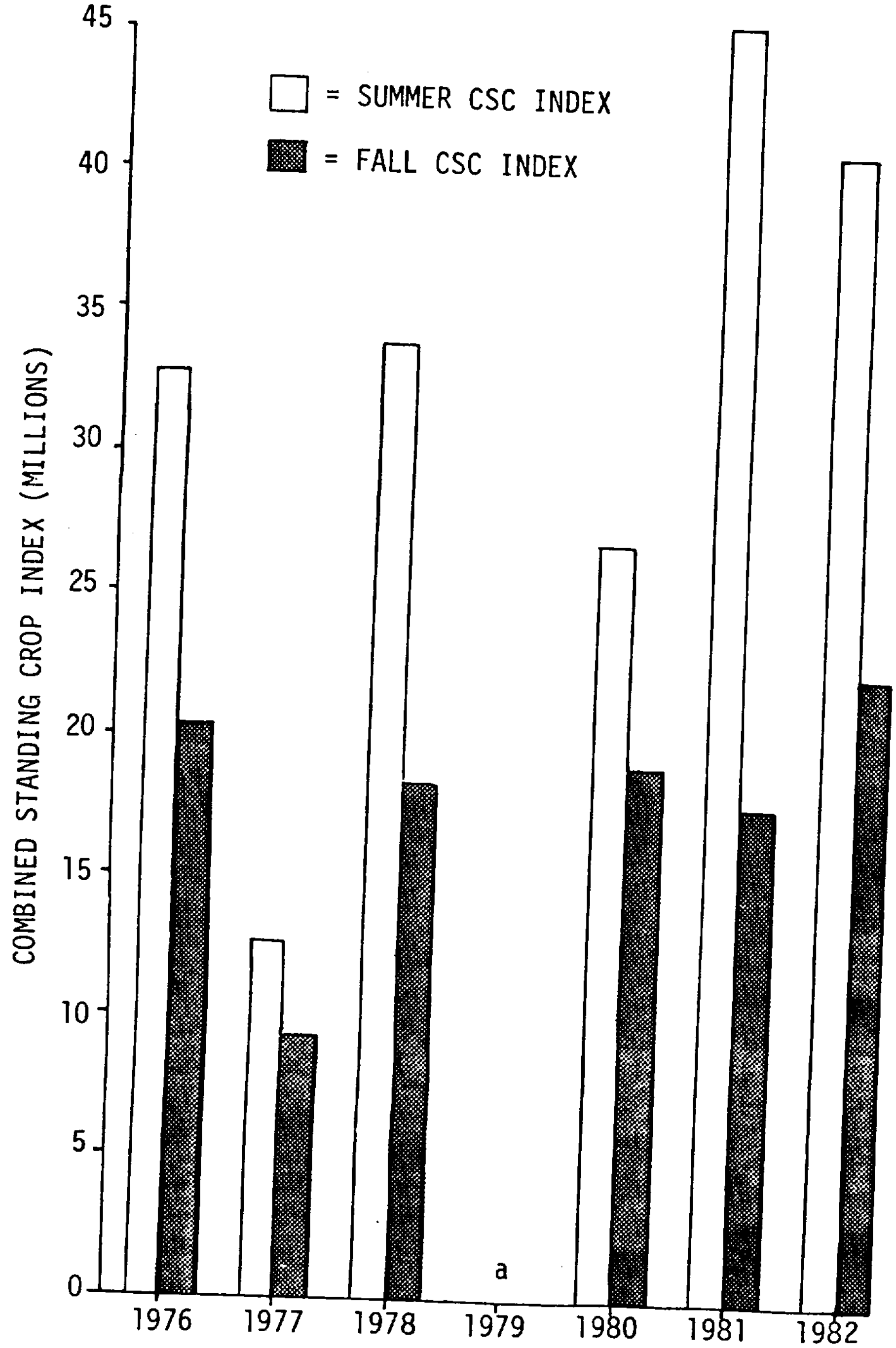


Figure 6.2-1. Combined standing crop (CSC) index of juvenile striped bass, summer (1 August) and fall (15 September) 1976-1982, Hudson River estuary.



[a] TI (1981) estimated the 1979 year class at 47 million on 1 August, making that the highest year, but did not report weekly CSC needed for calculation of index by regression.

Figure 6.2-2. Combined standing crop (CSC) index of juvenile white perch, summer (1 August) and fall (15 September) 1976-1982, Hudson River estuary.

6.3 COMBINED STANDING CROP CONFIDENCE INTERVALS

6.3.1 Weekly Combined Standing Crop Estimate

Combined standing crop, as an estimate of the weekly total number of young-of-the-year (YOY) striped bass and white perch in the Hudson River estuary, is subject to several sources of variation which must be identified and appraised in the process of calculating confidence intervals. In statistical terms, the weekly CSC is a "stratified total", representing the sum across 12 Hudson River regions of estimates of the total number of YOY striped bass or white perch in each regional stratum (shore, shoal, channel, and bottom). Stratum and regional totals are derived from the product of the mean density (number of fish per sample unit) of YOY striped bass or white perch and the number of sample units in the stratum or region. According to statistical theory, an unbiased estimate of the variance for the "stratified total" is obtained from the sum of the individual regional and stratum variances weighted by the square of the proportion of the entire system (number of sample units) found in each region or statum (Cochran, 1977: Theorem 5.5). Equation 24 (Appendix A) is used in this study to provide an unbiased estimate of standard error of the weekly CSC. These values are presented in the extreme right-hand column of the bottom row of each weekly CSC table in Appendix B. Confidence limits about the "stratified total" number of fish may be obtained from the product of the standard error for the "stratified total" and the t-statistic from Student's t-distribution (Cochran, 1977: Equation 5.15).

Degrees of freedom used to select the appropriate t-statistic may be estimated as the "effective" degrees of freedom, which takes into account variance heterogeneity among strata and regions (Cochran, 1977: Equation 5.16). With a high degree of variance heterogeneity among strata and regions (i.e., both low and high variance strata occur in the same week or region), a relatively low number of degrees of freedom are calculated and the resulting confidence interval is wide. Relatively narrow confidence intervals are obtained from the estimated degrees of freedom when variance is relatively homogenous among strata and regions (i.e., similar variance in all strata and regions within a week). The fewest effective degrees of freedom possible for a stratified mean or total are one fewer than the smallest number of samples taken in any stratum (Cochran, 1977). Since three samples are the fewest allocated in any stratum (Table 2.1-5), the widest (most conservative) 95% confidence interval about a weekly CSC estimate would be the product of the two-tailed Student's t-value for two degrees of freedom (4.303) and the standard error of the weekly CSC. The narrowest confidence interval (least conservative) would be based on the largest number of effective degrees of freedom, which is one fewer than the sum of the number of samples collected among all strata and river regions within a week (Cochran, 1977). A t-value of 1.970 would be used to determine the least conservative 95% confidence interval since the total number of samples allocated among all strata and regions is 300 (200 for Falls Shoals Survey, 100 for Beach Seine Survey; Tables 2.1-5 and 2.1-6).

Calculation of the effective degrees of freedom requires an assumption that individual sample density values within each stratum are normally distributed (Cochran, 1977). If the frequency distribution of density values is positively kurtotic (i.e., most densities are lower than the mean), the formula will overestimate the effective degrees of freedom and the resulting confidence interval about the CSC index will be narrower (less conservative) than the true precision (Cochran, 1977). Statistical examination of the frequency distribution for YOY striped bass and white perch densities (Table 6.3-1) revealed that, for each sampling gear used during 1982, extreme positive kurtosis existed in the data sets (a normal distribution has a kurtosis of 0) and these frequency distributions deviated significantly ($P < 0.01$) from a normal distribution. A logarithmic transformation, often used to normalize fisheries density data (Green, 1979), was not successful in normalizing the striped bass and white perch density data, primarily due to a high percentage of zero samples in the Fall Shoals data set (Table 6.3-1).

Failure to normalize the striped bass and white perch data sets indicates that the effective degrees of freedom estimate cannot be

TABLE 6.3-1. SUMMARY STATISTICS DESCRIBING THE FREQUENCY DISTRIBUTIONS OF YOUNG-OF-THE-YEAR STRIPED BASS AND WHITE PERCH SAMPLE DENSITIES FROM THE 1982 BEACH SEINE SURVEY AND FALL SHOALS SURVEY.

			FALL SHOALS SURVEY			
STATISTIC[a]	BEACH SEINE SURVEY[b]		EPIBENTHIC SLED[c]		TUCKER TRAWL[c]	
	X	$Log_{10}(X+1)$	X	$Log_{10}(X+1)$	X	$Log_{10}(X+1)$
STRIPED BASS						
N	500	500	750	750	250	250
Mean	11.3	0.6	1.4	0.1	0.01	0.002
St. Dev.	28.1	0.6	6.4	0.3	0.20	0.039
C.V. (%)	249	103	446	274	1581	1581
Skewness	7.8	0.6	8.1	3.0	15.8	15.8
Kurtosis	95.2	-0.7	87.4	8.7	250	250
N Zero (%)	42	42	86	86	99	99
Prob. Normal	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
WHITE PERCH						
N	500	500	750	750	250	250
Mean	27.2	0.8	2.0	0.2	0.2	0.04
St. Dev.	81.6	0.8	6.4	0.4	1.3	0.16
C.V. (%)	300	99	315	186	522	427
Skewness	9.3	0.5	7.1	1.8	8.3	4.5
Kurtosis	121.8	-0.9	68.7	2.3	87.1	20.5
N Zero (%)	39	39	74	74	94	94
Prob. Normal	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a]Statistic:
N = number of samples in 1982 season
Mean = mean density of fish per sample unit
St. Dev. = Standard Deviation
C.V. (%) = Coefficient of Variation (percent)
= Std. Dev. ÷ Mean x 100
Skewness = 0 for normal distribution
Kurtosis = 0 for normal distribution
N Zero (%) = percent of N samples which had a density of zero
Prob. Normal = probability that the data is a sample from a normal distribution

[b]Beach Seine Survey:
Sample unit = 450 m^2 seine sweep
Density X = number of fish per 450 m^2
Density $Log_{10}(X+1)$ = log transformed density

[c]Epibenthic Sled or Tucker Trawl:
Sample unit = 450 m^3 (approximate volume filtered by a standard tow for 5 min at 1.5 m/s.)
Density X = number of fish per 1000 m^3
Density $Log_{10}(X+1)$ = log transformed density

used to obtain a t-value for computing a 95% confidence interval about the weekly CSC estimate. Therefore, the best t-statistic which can be used to approximate 95% confidence limits is 4.303, because it is the most conservative statistic and results in the widest 95% confidence interval about the weekly CSC estimates of striped bass (Table 6.3-2) and white perch (Table 6.3-3).

6.3.2 Annual Combined Standing Crop Index

Confidence limits may also be computed for the summer (1 August) and fall (15 September) CSC indices. One method examined for this purpose was a variance scaling technique (Freese, 1962), which takes into account differences in sample size among sampling strata. However, since the CSC indices were calculated by regression rather than from a point estimate (peak), a simpler approach was appropriate. Standard errors from the fitted regression equations for the summer and fall CSC indices (Section 6.1.3) were used to calculate interval estimates about the predicted CSC indices for 1 August and 15 September for white perch (Appendix A, Equations 26 and 27). For the striped bass fall CSC index, however, a significant regression model was not found ($p < 0.05$), so the geometric mean was calculated and a simple 95% confidence interval was calculated using the t-statistic for degrees of freedom based on the number of weeks in the period minus one. The resulting confidence intervals for the 1982 CSC fall indices (Table 6.3-4) were narrower than both the most conservative and the least conservative 95% confidence limits for individual weekly CSC estimates (Tables 6.3-2 and 6.3-3). The summer CSC index for white perch had a confidence interval which was wider than for the fall index.

TABLE 6.3-2. MAXIMUM AND MINIMUM 95% CONFIDENCE LIMITS FOR YOUNG-OF-THE YEAR STRIPED BASS WEEKLY COMBINED STANDING CROP IN THE HUDSON RIVER ESTUARY, AUGUST-OCTOBER 1982.

WEEK BEGINNING MONDAY	COMBINED STANDING CROP (millions)		95% CONFIDENCE LIMITS			
			MAXIMUM (t=4.303)		MINIMUM (t=1.970)	
	CSC	S.E.	LOWER	UPPER	LOWER	UPPER
16 Aug	8.8	1.4	2.6	14.9	6.0	11.6
23 Aug	7.8	1.4	1.9	13.8	5.1	10.5
30 Aug	9.2	1.7	1.8	16.5	5.8	12.5
06 Sep	9.7	1.9	1.4	18.0	5.9	13.5
13 Sep	11.1	2.1	2.1	20.1	7.0	15.2
20 Sep	9.7	2.0	1.1	18.3	5.7	13.6
27 Sep	13.0	3.7	0	29.0	5.6	20.3
04 Oct	13.1	3.7	0	29.1	5.8	20.5
11 Oct	4.4	1.0	0.3	8.5	2.5	6.3
18 Oct	4.4	1.0	0.3	8.5	2.5	6.3

TABLE 6.3-3. MAXIMUM AND MINIMUM 95% CONFIDENCE LIMITS FOR YOUNG-OF-THE YEAR WHITE PERCH WEEKLY COMBINED STANDING CROP IN THE HUDSON RIVER ESTUARY, AUGUST-OCTOBER 1982.

WEEK BEGINNING MONDAY	COMBINED STANDING CROP (millions)		95% CONFIDENCE LIMITS			
			MAXIMUM (t=4.303)		MINIMUM (t=1.970)	
	CSC	S.E.	LOWER	UPPER	LOWER	UPPER
16 Aug	29.5	10.6	0	75.1	8.7	50.4
23 Aug	27.9	10.6	0	73.4	7.0	48.7
30 Aug	26.2	5.8	1.3	51.1	14.8	37.6
06 Sep	28.9	5.9	3.5	54.3	17.3	40.5
13 Sep	20.8	3.8	4.3	37.3	13.3	28.4
20 Sep	18.7	3.8	2.5	34.9	11.3	26.1
27 Sep	17.8	2.5	7.2	28.4	12.9	22.7
04 Oct	17.9	2.5	7.2	28.6	13.0	22.8
11 Oct	16.5	3.6	1.1	31.9	9.5	23.6
18 Oct	16.5	3.6	1.1	31.9	1.1	31.9

TABLE 6.3-4. CONFIDENCE LIMITS (95%) FOR THE 1982 COMBINED STANDING CROP INDICES FOR STRIPED BASS AND WHITE PERCH, HUDSON RIVER ESTUARY.

				COMBINED STANDING CROP (millions)		
FISH SPECIES	LIFESTAGE	INDEX	df	LOWER CONFI-DENCE LIMIT	CSC INDEX	UPPER CONFI-DENCE LIMIT
Striped bass	YOY	Summer		Not estimated		
		Fall	4	8.8	10.4	12.4
White Perch	YOY	Summer	5	29.7	39.0	55.1
		Fall	3	19.0	22.1	25.6

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